FINAL RI

DEVELOPMENT OF CAST AIRCRAFT COMPONENTS

CONTRACTOR

ALLOY ENGINEERING AND CASTING CO.

CHAMPAIGN, ILLINOIS

DEPARTMENT OF THE AIR FORCE

INDUSTRIAL RESOURCES DIVISION

AIR MATERIEL COMMAND

CONTRACT NO. AF33(038)-18900

CHANGE ORDER NO. 4

ALLOY ENGINEERING AND CASTING COMPANY

CHAMPAIGN, ILLINOIS

Contractors To Air Materiel Command U. S. Air Force

CASTING POTENTIALS PROJECT

ACKNOWLEDGMENT

The Steering Committee who took part in conferences with Lt. General Rawlings, Commanding General, Air Materiel Command, have requested that we express their appreciation, with our own, to him and to the Officers of USAF Headquarters Command, and to all Officers and civilian personnel in both Commands who have sponsored, administered, and implemented the effort of this Project.

The scope of this Project, as originally set forth, was modified by Change Order No. 4 dated 10 December 1952 to the effort herein reported. Prior findings of the Project applicable to Casting Potentials beyond this report are available, and are covered by recommendations herein contained.

Contractor acknowledges, with deep appreciation, the assistance of the Project Advisory Committee, and the extensive contribution of time and travel made by Messrs. Sutton, Danse, and Roehm, - the Steering Committee.

We are indebted to Mr. J. H. Kindelberger, Chairman, and Mr. R. L. Schleicher, Chief of Stress of North American Aviation, Inc., - to Mr. Emric Bergere, Chief Production Engineer of Douglas, Long Beach, - to Mr. Ken Ellington, Vice President of Republic, Mr. Ray Ryan, formerly Vice President of Convair, for their interest in Casting Potentials and their educational contributions to Contractor's understanding of aircraft requirements;- also to Mr. William Bean, Stress Consultant to Project who also conducted the stress tests being reported.

It was predicted, at the start of this Project, that the principal obstacles to effective development of casting potentials were psychological and in inverse proportion to individual cognizance of advanced casting technology and controls. This "Minimum Token Effort", as described in Contractor's bid, can be considered as educational.

If interest in aircraft and casting industries can be judged by the increased activity of industry committees and individual companies relative to cast aircraft components, some progress has been made.

H. H. Harris
Project Director

31 May 1953

Project: A.—Survey Aircraft Industry for Potential Casting Utilization. B.—Survey Known Casting Process. C.—Re-design Aircraft Components for Casting by Selected Processes. D.—Pilot Produce Casting for Evaluation.

FINAL ENGINEERING REPORT

DEVELOPMENT OF CAST AIRCRAFT COMPONENTS

DEPARTMENT OF THE AIR FORCE
AIR MATERIEL COMMAND

U. S. A. F. CONTRACT NO. AF 33 (038)-18900
Change Order No. 4

CONTRACTOR

ALLOY ENGINEERING & CASTING COMPANY
Champaign, Illinois

MAY 31, 1953

ERRATUM SHEET

FOR

FINAL REPORT

DEVELOPMENT OF CAST AIRCRAFT COMPONENTS
CONTRACT No. AF 33 (038)-18900

ALLOY ENGINEERING & CASTING COMPANY
Champaign, Illinois

SECTION I:

Introduction, 4th Par. Substitute "comparative ease" for "comparatively ease".

B - Major Objectives, Page 2, 4-a: Substitute "excel" for "excell".

B - Major Objectives, Page 2, 4-b: Substitute ".040" for ".004".

B - Major Objectives, Page 3, 6: Substitute "excel" for "excell".

SECTION II:

A - 2, Page 2, Par. "Sectional Uniformity": Substitute "superior" for "suprior".

A - 2, Page 3, d: Substitute "application of advanced casting" for "application advanced casting".

A - 2, Page 4, Par. "Comment", 1st line: Delete "as", to read "offers many advantages".

A - 2, Page 4, Par. "Comment", 3rd line: Substitute "or" for "of".

B - 2, right-hand page, 2nd Par: Substitute "blasted" for "blased".

C - 2, 2nd Par., 4th line: Substitute "load" for "lead".

D - 1, Note 1: Substitute "implementation" for "implement".

D - 2, Photo #3, 4th line: Substitute "hole" for "hold".

D - 2, Par. "Conclusion", 10th line: Substitute "thick attachment end, which tapers into 1/8" section in side walls, which increases in taper to 1/4" section in flange" for "thick attachment end of which tapers into 1/4" section in side walls, which tapers to 1/4" section in flange".

ERRATUM SHEET

Page 2

SECTION V:

4 - Par. "Relative to Aluminum Castings", D, 2nd line: "Non-forgeable" should be in parentheses.

6 - Par. "Shell Molding", C, 2nd line: Substitute "use in foundries" for "use for foundries".

7 - Par. "Relative to 'Precision' Castings", A, 6th line: Substitute "non-producibility" for "unpredictability".

7 - Par. "Relative to 'Precision' Castings", C, last line: Add to last sentence ", by other process".

8 - Par. "Relating to Requirements for Precision in Castings and their Attainment in Process", H - 1: Substitute "In producing" for "Producing".

9 - Par. "Re: Design Latitude", J: Substitute "patterns, from which castings" for "patterns from which castings".

10 - Par. "Facilitation of Casting Process", 3rd Par., 5th line: Substitute "from the sum of" for "from some of".

11 - Par. "Re: Comparative Economics of Casting Process", A, 1st line: Substitute "approximation of final size" for "approximation of size".

14 - Par. "Direct Substitution of Cast Components in Production Aircraft Holds Minimum Potential", A, 3rd and 4th lines: Substitute "provides" for "provide".

Par. "Conclusions", A, 2nd line: Substitute "more of various" for "more various".

TABLE OF CONTENTS

SECTION

I INTRODUCTION

This report is intended to furnish the Air Materiel Command pertinent information on work done by the Contractor on AMC-USAF Contract AF 33(038)-18900, Change Order #4.

Known as the "Casting Potentials Project", its objective is to evaluate the basic concept of pouring molten metal directly to close approximation of finished form, thus materially reducing fabrication, labor and machining costs and related facilities inherent in conventionally employed, less direct and more complex, production methods. The REPORT COVERS: (A) The engineering stress evaluation and redesign of aircraft components from steel and aluminum forgings to high-strength steel and aluminum castings of equivalent strength-weight ratio. (B) The experimental production of castings by expedient means for physical stress tests for initial design evaluation. (C) The physical testing of such castings preparatory to the final design pilot production of HIGH INTEGRITY CASTINGS, BY ADVANCED PROCESS, TO REPLACE FORGINGS AND FABRICATIONS IN AIRCRAFT.

THE WORK REPORTED COVERS Douglas C-124A Nose Landing Gear Trunnion and two Chase C-123-B components consisting of Main Landing Gear Drag Link Attachment Fitting and Trunnion.

Landing gear components, because of their minimum integration with airframe structure, and comparatively ease of replacement, appeared to be the most expedient selection under the limitations imposed. Each part was studied and redesigned for production as a casting. Designs were based on maintaining the strength-weight ratios of existing forgings to provide a basis for comparative study. Such highly stressed parts are currently produced by specialized and highly developed process. They are representative of the best materials, metallurgy and process currently employed in airframes.

THIS INITIAL APPROACH was limited to the engineering compromise of substituting cast components for those whose form, and integration in assembly, was initially determined by design considerations dictated by other process.

The current effort is, essentially, "educational". The designs, materials and physical expectancies herein presented are no more representative of results attainable, with experience and process improvement, than were comparable experimental components as first experimentally produced by contemporary processes.

Contractor is currently extending successful research and development in advanced casting process to sizeable pilot production through integrated company and Navy owned facilities.

The casting design-process concepts motivating this effort can be expediently extended to sizeable pilot production employing such facilities, and thereafter extended as results and needs may indicate.

SECTION I

OBJECTIVES: (A) OF EFFORT REPORTED.

Objectives of Effort Reported.

1. To redesign (within limitations imposed by necessity of interchangeability in complex assemblies) for ultimate production as high-integrity, high-strength steel and aluminum castings, the following aircraft components.

   a. Chase Aircraft Company C-123-B Main Landing Gear Drag Link Attachment Fitting, Part No. 8B-310307.

   b. Chase Aircraft Company C-123-B Main Landing Gear Trunnion, Part No. 8B-410020.

   c. Douglas Aircraft Company C-124A Nose Landing Gear Trunnion, Part No. 8897A-14A-1.

2. To make preliminary redesigns of the above parts for casting and tentative stress analyses.

3. To make design corrections as indicated by stress analyses, - make models for study purposes, - make final theoretical stress analyses.

4. Complete designs and make simple wooden patterns suitable to produce a limited number of castings for stress evaluation of form and material distribution.

5. To make sample castings from above patterns: (A) Steel castings to be made in sand in the Contractor's regular production nickel-chrome H.R. alloys for design-stress evaluation only. (B) Aluminum castings to be produced in conventional analyses in ceramic molds.

6. To make stress loading tests, to check the adequacy of design and determine strength-weight comparison to corresponding forgings.

7. To make corrective design changes if tests indicate the advisability of such action.

8. To present Contractor's casting design-process engineering philosophy and related theoretical and applied concepts of design-material stress-fatigue evaluation previously employed to successfully predict service fatigue-life expectancy.

Objectives as above are considered a "token" effort directed toward Major Objectives, outlined on page following.

SECTION I

B. MAJOR OBJECTIVES

(As projected by Contractor and Steering Committee of Casting Potentials Project Advisory Committee)

I. PRIME OBJECTIVE:

TO INCREASE PRODUCTION OF AIRFRAMES, MISSILES AND ENGINES at reduced cost of material, labor and facilities by more direct and economic production of superior metal components, - by expediently employing and extending U. S. superiority in advanced casting process.

II. OBJECTIVES IN ATTAINMENT OF PRIME OBJECTIVE:

In approaching Prime Objective, broadly increased understanding, leading to some degree of acceptance and support by many in Government and industry, is essential. To this end, Major Objectives in service of the Prime Objective are:

TO EXPEDITE COGNIZANCE:

A. OF GOVERNMENT AND MANAGEMENT, RE:

1. The reduced design limitation, the increased production potential and the resultant savings in material, labor, facilities and transport, - by POURING METAL DIRECTLY TO CLOSE APPROXIMATION OF FINISHED FORM.

2. The broad significance, in terms of possible contributions to U. S. air superiority, of high volume, low-cost producibility of wings, skins, large structural components, control surfaces and entire missiles and strength-weight, production and economic advantages which increase with size.

3. Re-evaluation of:

   a. The Large Forging Program (German 1943) in light of projected potentials of U. S. Advanced Casting Process; in terms of technology, producibility, time, facilities, size limitations, transport, economics and obsolescense.

   b. The calculated risk of "hedging our bet on a touted 'favorite' by a ten-per-cent gamble on a promising 'long shot'."

B. OF AIRCRAFT DESIGNERS, RE:

Expediting comprehensive evaluation by top Aircraft Engineers of the unique physical and producibility advantages which are process-inherent in flowing FLUID metal, rather than forcing SOLID metal, or "hogging" slab metal to

B. MAJOR OBJECTIVES (continued)

desired form, (with greatly reduced facilities, machining and fabrication required). Pilot production, tooling for volume production of large components by advanced U. S. casting process, - designed for new aircraft with full employment of casting-design-process engineering, is considered attainable within the time required to design new aircraft.

SUCH CASTING PROCESS-INHERENT ADVANTAGES (attainable in max. degree in Advanced Casting Practice) ARE CONSIDERED TO BE:

1. Improved strength, stiffness and weight reduction through continuity of form and metal (less weight, less "stress raisers", less "bits-and-pieces".)

2. Tapering sections integral, proportional, "stiffners" and unlimited contours (cast to form without machining) provide maximum strength, minimum weight (less "chips", more airplanes and missiles.)

3. Economic, small or large volume producibility of high-strength-weight ratio "tublarform", cored and continuous envelope forms. (a. - not practically forgeable. Believed not otherwise producible with equivalent strength-weight ratio for the high loadings currently projected. b. - can be gas-tight.)

4. Physical advantages: Controlled high-integrity cast structures have equal longitudinal and transverse properties, whereas mill products and forgings do not.

   a. High integrity steel castings can be currently designed-for-process and produced by advanced process (with 180,000 lbs. to 200,000 lbs. plus psi. ult., 8 to 10% elongation) to equal or excell steel forgings in a high percentage of applications and replace light metal forgings with equal strength-weight in many applications.

   b. For high skin temperature conditions, alloy steel castings, producible in .040" sections, rate thorough evaluation.

   c. Advanced process aluminum castings with properties (60,000 lbs. ult., - 10% elongation) approx. 50% above conventional process castings, are producible with existing facilities, can be expediently advanced to replace a high percentage of present and projected forged and "hogged" large aircraft components.

   d. Process advances in aluminum are largely applicable to magnesium. (Porous oxide-contaminated magnesium castings, impregnated with resins, can be replaced by sound stronger-lighter magnesium castings by application of known casting technology.

5. Many high-strength materials are better adapted to producibility by casting by advanced processes and controls (this opens a large field of neglected metallurgical development leading to:

B. MAJOR OBJECTIVES (continued)

(a) improvement of U. S. aircraft materiel. (b) broadening of production base.

6. Cast heat-resistant alloys excell mill products. Throughout U. S. industry, castings have proven superior in resistance to deformation and in service life. Improvement of gas turbine service life, producibility and production economics is considered expediently obtainable by employment and extension of available advanced casting process. "More pounds of 'chips' than engines are currently produced.")

7. Casting Design-Process Factors. Highly integrated factors of form, - size, - section, - process, - and chemistry-structure relationship determine degree of uniformity and relative physical properties and fatigue life expectancies. (These must be comprehensively understood and employed in direct relation to specific form to achieve optimum (or even logical) employment of castings in aircraft.)

C. OF METALLURGISTS RE:

1. The dominate role of structure, (i. e. grain size and orientation) in physical properties, particularly elongation and fatigue life, "stiffness", also machineability and corrosion resistance. (Chemistry-structure relationship is currently ignored in aircraft casting specifications. It is a principal service-life controlling factor in heat and corrosion resistant alloys, in all metals whose as-cast structure cannot be grain-refined by heat-treatment, and to varying degrees in other metals.)

2. Specifications and Inspection Procedures.

a. Consideration is indicated, in consultation with casting engineers, of: (1) Government Aircraft Casting Specifications, (2) "Casting Factors" and (3) "Standard" test-bars (as currently applied to conventional castings) to facilitate, rather than irrationally impede expedient employment of advanced process castings when such castings are demonstrated as acceptably interchangeable with forgings and fabrications.

b. Similar cooperative effort is indicated to formulate "grain-size" and "oxide count" Standards and inspection procedures applicable at source, - to include and specify process controls keyed to improved test-bars which realistically approximate, and can be specifically keyed to, the varying metal sections in specific cast configurations.

D. OF STRESS ENGINEERS, RE:

1. Limitations of Exterpolated Test Data.

Physical values obtained from "standard" cast test-bars cannot be logical-

B. MAJOR OBJECTIVES (continued)

ly exterpolated into design calculations, if optimum utilization of the true sectionally related properties, derived from controlled chemistry-structure relationship in a given metal section, is to be realistically approached. The physical properties in both as-cast and heat-treated castings (refer to C, No. 1, above) insofar as they are determined by grain size and reorientation, must be factually considered, and true values for a given metal in a given section with a known, predictable and controllable structure, employed.

2. Structure is determined by local cooling rate, or the time required for a given cast metal-section to solidify and cool. Thin sections, poured at the same temperature, have materially finer structure and superior elongation, as compared to thicker sections of the same casting. Many cast metals show two or three times the elongation, when cast in sections below 1/2", than that indicated by "standard" test bars. Two identical castings, poured from the same metal, at the same temperature, will have substantially identical structure and related properties in similar sections.

3. Lack of elongation has been a major obstacle to the employment of many high strength alloys as castings. Many such materials, both ferrous and non-ferrous, have materially improved elongation in thin section. The merit of thin wall "tublarforms", with minimum sectional variation and gradation of adjacent varying section, becomes evident. By specifying structure, in relation to section, in specific materials, fatigue resistance can be designed in. Increased load carrying ability, and dependably predictable performance, are attainable.

4. Casting Factors. Elimination of "Casting Factors", as applied to high-integrity steel castings produced by advanced process (with each casting keyed by grain size coupons and checked by Comparoscope), can be expediently justified. Material reduction of such "factors", as applied to specific classifications of aluminum castings in commercial production by advanced processes, can be justified, leading to progressive reduction and elimination.

E. OF CASTING INDUSTRY, RE:

1. The need for materials and processes to produce aircraft and missile components, with increased strength-to-weight ratio, has been tremendously accelerated by the greatly increased, and continuously increasing, speeds and loads of modern aircraft. (Castings have long been used in aircraft and were employed in many high stressed applications in World War II. Such castings have largely been replaced by forgings or fabrications. Those remaining are in "low stressed" applications. Technological ad-

B. MAJOR OBJECTIVES (continued)

vances in materials and processes in other industries, and, particularly, in highly subsidized industries, have progressed far beyond casting process development.

2. The need for drastic and continued up-grading of casting process, process controls and inspection procedures is indisputable, and is mandatory to projected increased replacement of forgings and fabrications with high-integrity castings, as herein projected.

3. Aircraft designers currently deduct substantial percentages (known as "Casting Factors") of the physical properties indicated from test-bars in designing cast aircraft components. "Casting Factors", varying up to 50% with different companies, are considered necessary to provide a "safety factor" to cover irregularities in chemistry, structure, soundness and physical properties. Such "factors" are arbitrarily arrived at by historical experience and "guesstimation".

(Note: Misapplication of fabrication design experience to castings, unrealistic specifications, procurement procedures, pattern equipment and inadequate at-source inspection are contributing factors to casting "shortcomings". The major factor, however, is unpredictable non-uniformity resulting largely from "floating" variables considered largely inherent in "conventional" casting practice.)

4. The need to design aircraft components, with comprehensive employment of advanced casting design-process engineering, including full utilization of modern stress testing techniques. Such engineering, backed by adequate process, facilities and controls, offers the most logical approach toward effectively utilizing the advantages inherent in casting, and, enhanced and supplemented by all process improvements, to compete effectively, in strength-weight ratio production and economics, with aircraft forgings and fabrications.

5. The need for vastly improved dimensional control of large castings to effect reduction of machining.

   a. This must be achieved through drastically up-grading:

      (1) Pattern making tools and skills
      (2) Foundry equipment and tooling
      (3) Process controls
      (4) Inspection procedures

   b. The cost of facilitating such process is infinitely small, as compared to the cost of machining facilities replaced.

   c. By effectively producing, directly in the foundry, cast forms to close approximation of the final dimensional and surface requirement of

B. MAJOR OBJECTIVES (continued)

aircraft component (rather than wastefully producing an oversize piece with a rough surface and machining it to size), incalculable savings in labor, facilities, scrap and transport are possible. High-integrity castings so produced will justify a fifty to several hundred per cent increased price over a conventional "rough" casting, in limitless applications. Investment in tooling and technology, with private or subsidized facilities, should be quickly amortized, giving casting producer, - with acumen to perceive the need for high integrity castings in Defense production, - an opportunity to up-grade his entire operation, retard obsolescence and compete more effectively in industrial markets.

d. Scientific Heat-Treatment. To effectively produce the improved and more uniform physical properties mandatory in aircraft castings (and urgently needed in all Defense and civilian industry that is conscious of scientific stress evaluation in designing for high-strength-to-weight ratios), drastic up-grading in conventional foundry heat-treatment equipment and process is mandatory. (Leading foundries have found crude furnaces and batch quenching will not do an acceptable job and are employing modern equipment in advance production.)

SECTION I

ABSTRACT OF FINAL ENGINEERING REPORT

Report covers a "token" engineering and production effort to provide indication of Casting Potentials in replacement of forged and fabricated aircraft components.

The effort reported sought to attain the best possible compromise in selecting components with a maximum of integration and attachment. Landing gear components provided the best selection available, under the circumstances and budgetary limitations.

Prints of components and attachments, with complete theoretical stress analyses, were supplied by aircraft manufacturers. Contractor inspected aircraft, evaluated functional requirements, checked theoretical stress analyses on present components, produced preliminary designs, studied such preliminary designs by production of models and complete theoretical stress analyses, and made design corrections indicated.

Castings were produced solely to provide forms for design evaluation by physical testing. (One component was later cast at private expense to indicate producibility and physical properties of heat treated alloy steel castings.)

COMPONENTS REDESIGNED AND/OR PRODUCED ARE AS FOLLOWS:

1. Chase C-123-B Main Landing Gear Trunnion, redesigned from an I-beam section, 41-40 steel forging* to a high strength steel casting** (analysis - Section II, Item D, #3). Casting was designed to material strength of 150,000 psi ult. and weighed 17.25 lbs; as cast, finished, 16 lbs., as compared to finished forging weight of 20.5 lbs. (Test of samples cut from section of steel casting produced of same design and cut, subsequently, pulled 200,000 psi ult.) (Note) * - See Section II - D - 3.
** - Rough forging weight not available.

PHYSICAL STRESS-TEST EVALUATION OF DESIGN INDICATED:

a. That: very minor modification, from pre-final to final design, was indicated to produce a casting with function, - and fatigue life expectancy, - equal to the forging.

b. That: the forging could be advantageously replaced by a casting of the final design with a 21.9% saving in weight.

c. That: the design was readily producible as a high integrity, high strength steel casting by advanced casting process.

d. That: material savings in tooling and facilities, - with less machining, and at materially reduced overall cost, - will result.

2. Chase C-123-B Main Landing Gear Drag Link Attachment Fitting was redesigned from an I-beam section, 14S-T6 aluminum forging (finished wt. -2.8 lbs. **);- to

a "tublarform" aluminum casting of 10 Mg. -Al. alloy, approximating "220". Casting was produced (wt. rough - 2.34 lbs., finished - 2.1 lbs.) Casting and forging were simultaneously subjected to design evaluation by physical stress testing.

PHYSICAL STRESS-TEST EVALUATION OF DESIGN INDICATED.

a. That: a minor design alteration was desirable, increasing weight of casting to 2.2 lbs. (increase of .1 lb.)

b. That: the weight reduction of the casting, with such increase, represented a weight saving of 21%, as compared to the forging.

c. That: the forging could advantageously be replaced by a casting of Contractor's final design.

d. That: aluminum castings, with superior tensile strength and adequate elongation, can be produced by advanced casting process in commercial production.

e. That: material savings in tooling, facilities and overall production cost of the casting (as compared to the forging) will result.

3. Douglas C-124-A Nose Landing Gear Trunnion was redesigned from an I-beam section aluminum forging (60 lbs.) to two alternative casting designs, both of designed strength-weight, identical to the forging (based on 170,000 psi ult.). Redesigns were developed by application of advanced casting design-process engineering procedure and were fully stress evaluated by theoretical stress analysis in accordance with accepted aircraft industry practice. Both designs were projected for comparative evaluation, selected design to be produced by Contractor's advanced casting process employing ceramic molds, Cen-T R-I-P-etally cast. Production of one of the above designs, or of another large landing gear component, designed as a casting, is included in Recommendations.

SECTION I. INTRODUCTION

ENGINEERING PHILOSOPHY   A. DESIGN APPROACH

The design techniques employed in the design of subject castings are believed to be the most efficient, accurate and practical methods yet developed by engineers engaged in structural research. Load carrying ability of a structural component is directly related to its stress distribution and its material and material processing. Simply stated: "Optimum structural efficiency is achieved when these three factors are properly balanced -- (1) Material, (2) Shape and (3) Load."

Operating stress is a function of shape and load. When operating stress is compatible with material strength, failure is prevented. Today, material strength can be established by routine laboratory procedure; stress distribution (shape analysis) also can be established by routine laboratory procedure; but accurate load determination must await actual flight data. No design analysis, regardless of how rigorous it may be, is any better than its load analysis. Design loads for radically new aircraft must be based solely upon theoretical considerations -- they can be seasoned with experience. The structural designer on such a project is faced with a dilemma; he must design accurately a component to sustain a load, whose nature, origin, frequency and magnitude is not accurately known. Therefore, his analytical solution, at best, is but a trial solution.

Years of statistical flight data will be required before service loads are pinpointed with the same degree of accuracy as that readily achieved by a laboratory analysis of material and shape.

In lieu of factual data on material, design and loads, the aircraft designer must increase his margins of safety or be prepared to accept some unexplained and unexpected structural failures in service. The recommended engineering solution to this dilemma has three phases:

Phase 1. Trial solution by theoretical and analytical computations.

Phase 2. Structural tests applying calculated loads to experimental components in order to evaluate stress distribution and material strength. Make necessary corrections in both prior to service failure.

Phase 3. Flight tests. Determine actual service loads. Review Phases 1 and 2 and converge to final design prior to production release.

SECTION I. INTRODUCTION

ENGINEERING PHILOSOPHY B. CASTING DESIGN-PROCESS CONSIDERATIONS

Castings, by the fundamental nature of the casting process, differ radically from metal forms produced by other process. A casting is "born to size". It emerges as an entity, as the fluid metal solidifies to solid form. Its as-cast physical properties are determined, to a large degree, by its grain size and orientation of structure, by its homogeneity, continuity and freedom from oxides and non-metallics.

In metals which cannot be completely altered in structure by heat treatment, mechanical properties are determined, in large degree, by the "thermal path" and related thermal and physical factors. These "vary all over the map" in "conventional" foundry practice. The predictable uniformity of castings is in direct relation to the control of these and other variables in the casting process. Such variables in commercial castings have long been known, partially understood, and, in general, have been controlled only to the degree dictated by economic necessity in more or less effectively meeting the specifications of basic industry.

Industry, generally, does not employ scientific theoretical stress-evaluation and stress-testing in design development, and has few mandatory requirements of strength-weight ratios. (If it did, the knee-brace school of casting design would be extinct and fabrications would have fewer sponsors.) The variables of material distribution, in relation to load in conventional (i.e. non-scientific) design, vary, in general, far more than the physical variables in the castings produced by conventional (i.e. non-scientific) casting practice.

Any material increase in the use of castings in aircraft must come about through reorienting the thinking of both the designer and the casting engineer to factual consideration and understanding and effective employment of casting design-process technology. Only through such cooperative effort will the vast potential of the casting process, - to produce more functional forms with superior mechanical properties in a vastly greater variety of size and form, than are producible by forging, and with greater uniformity of load distribution than is possible by fabrication, - be employed.

<u>BACKGROUND</u>: Thirty-five years of specialization in the design and production of heat and corrosion resistant alloys has contributed materially to evaluation and partial reduction of Contractor's ignorance in regard to the control and extension of casting performance in such strenuous service. Such alloys cannot be refined in structure by heat treatment. In the early 1920's, it was determined that fatigue life of such alloys <u>was inversely proportional to grain size</u>, and that understanding of specific service conditions, and integration of stress, structure and casting technology, was inseparable and mandatory. Extensive research, directed to the control of chemistry-structure relationship, was undertaken.

A high percentage of heat resistant alloys is employed in the supply of high temperature "tooling" for heat treating departments of high production industries. This has provided a unique opportunity to study: (1) relative fatigue of H. R. alloy structures, as produced by casting, and, - (2) the effect of heat treatment on all metals and alloys. In no other field are ranges and varieties of stresses encountered to compare with the violent thermal shock in such service. The stresses generated within castings, subjected to irregular heating, are vastly greater than the load stresses. Ultimate failure, in many instances, results largely from "cold working" of relatively cold casting areas, by the forces of expanding adjacent areas subjected to unequal heating. The short life-cycle, in such severe service, has the advantage of providing stress-fatigue failure data at a greatly accelerated rate in applications where ultimate fatigue is certain and its progress observable.

The data obtained from such experience, and Contractor's extensive private and Government sponsored research and development, - (directed at control of grain size and orientation of structure, as well as dimensional control), - has provided some understanding and a lesser degree of specific knowledge. This is considered fundamental and broadly applicable, in varying degree, to the improvement of castings in most metals and alloys. The degree of ignorance remaining, after the devotion of a lifetime of effort, is formidable, but no insurmountable obstacles to its continued and accelerated reduction, and a revolutionary advance in Casting Potentials, are in view.

IT IS IMPOSSIBLE TO GENERALIZE. Castings must be considered in relation to specific service, form, material and the casting process employed. The basic difference between light metal and steel castings is that the former, due to high metallic oxidation rates, contain a far higher degree of oxides, when conventionally melted and cast in contact with air. Light metal castings have been more-or-less accurately described as "a network of metal surrounded by oxide, or vice versa". There is no excuse, in the light of available science and engineering, for this to exist. The variations in density, continuity and related uniformity and predictable physical properties, function and fatigue life of light metals cast by conventional process is, in no sense, characteristic of steel castings.

CASTINGS VS. FORGINGS. Sound, clean, cast steel is as dense as any forging. Castings and forgings of identical chemistry can be heat treated to attain equal physical properties. Any special "directional" physical properties in forgings is brought about by the "work" applied to the original castings (ingot) successively to the billets from which they are produced. (Such directional "work benefit" is lost by heat treatment to obtain uniform structure.)

"Directional properties" result from the degree of "work" and flow which results from pounding, squeezing or squirting metal in dies. Such flow varies with each configuration and, in general, there is a minimum probability that the distribution of "superior directional-properties", or the related, inferior, "trans-directional properties" will be distributed in optimum relation to load. Further, the load may "zig", when expected to "zag". Certainly, the multi-directional properties of scientifically designed, cast and heat treated steel castings need not suffer, in comparative merit, for application in a great majority of cases where any forging is applicable. A vastly greater number of steel casting applications are made possible by less design restriction. The casting-process-inherent advantages previously set forth can provide superior forms which permit equal load-carrying ability with less weight: Equivalent to proportional strength increase.

In approaching the redesign of aircraft components:

1. currently produced as steel forgings, - for redesign as steel castings,
2. currently produced as aluminum forgings, - for redesign as steel castings,
3. currently produced as aluminum forgings, - for redesign as aluminum castings,

Contractor endeavored to create, within imposed limitations, forms adaptable to casting as "tublarform" cored sections employing minimum metal sections, and with a minimum of change in section and mass. This is desirable, not only for structural control and uniformity in casting, but also for structural control and uniformity in heat treatment. The residual stresses in both castings and forgings are "relieved", in varying degree, in different metals, by heat treatment. Their understanding and control is an important factor in the casting design-process technology employed.

Note A: It should be specifically noted that no attempt has been made to include in the preceding "Design Approach", or in the stress calculations, herein contained, consideration of the physical properties varying with, and specifically related to, section. This cannot be undertaken until the sectionally related properties, in specific metals and sections, can be established by testing of a number of castings. Such consideration is only of academic interest until many more castings have been produced under controlled conditions, and keyed, by grain size coupons, to Comparoscope inspection and other controls, to insure repetitive production of castings of predictable uniformity. (It is noted that samples cut from the casting showed superior properties to test-bars.)

Note B: The castings produced were made solely to provide forms for stress evaluation, and produced in sand molds by modified conventional process. The designs, very slightly modified, as a result of evaluation by physical stress testing, are recommended for production in ceramic molds under controlled atmosphere by Cen-T-R-I-P-etal process.

Note C: Recommended Heat Treatment:- Heating in forced convection furnaces. Quenching in heated-oil-cooling-media, employing best approach to uniform heat extraction, proportional to surface-mass relationship, through locally controlled velocity and flow of coolant.

SECTION II

CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

Chase Part No. 8B-310307 Chase Aircraft Company, West Trenton, New Jersey

REDESIGNED FROM "I" SECTION STEEL FORGING TO "TUBLARFORM" HIGH-INTEGRITY, HIGH-STRENGTH STEEL CASTING

THIS SECTION INCLUDES:

A. DESIGN - Perspective Sketches of Comparative Designs (next page)

1. History of Design Development.
2. Philosophy of Tublarform Design Casting and Fatigue Life Experience.
3. Chase Dwg., Chase Part 8B-310307, and Contractor's Dwg. CP-518.
4. Stress Analysis by Chase Aircraft Company.
5. Stress Analysis by Contractor.

B. Experimental Production of Castings in Contractor's Normal Heat Resistant Alloys from Wooden Patterns in Sand Molds, to Provide Physical Forms for Stress Evaluation Only.

(Note: Above procedures are preliminary to Contractor submitting proposal for production of parts in High-Integrity, High-Strength Steel castings in ceramic molds by Cen-T-R-I-P-etal Casting Process.)

1. Photographs of Mold, Pattern, Core Boxes and Ceramic Gating.
2. Photographs of Experimental Castings.
3. Typical Analyses and Physical Properties of Nickel-Chrome H. R. Alloy Stress-Test Model Castings.

C. Illustrated Report of Stress Testing and Evaluation of Nickel-Chrome Alloy Stress Test Model Castings for Design Evaluation Only.

D. High-Strength, Heat Treated Steel Castings Produced from above Patterns. (Work not specified in Contract.)

1. Purpose and Procedure.
2. Photographs of Trial Nickel-Chrome Alloy Casting and High-Strength Steel Castings Produced by General Alloys Company, Boston, Mass.
3. Technical Data Re Metallurgy, Production and Heat Treatment of High-Strength Alloy Steel Casting Produced and Results of Tensile Test by Independent Laboratory.

Fig. 1 shows original Chase C-123-B part, a lightened I-beam section steel forging. The part bolts to the airframe structure in a vertical position forming attachment for main landing gear drag link fitting.

Section A-A

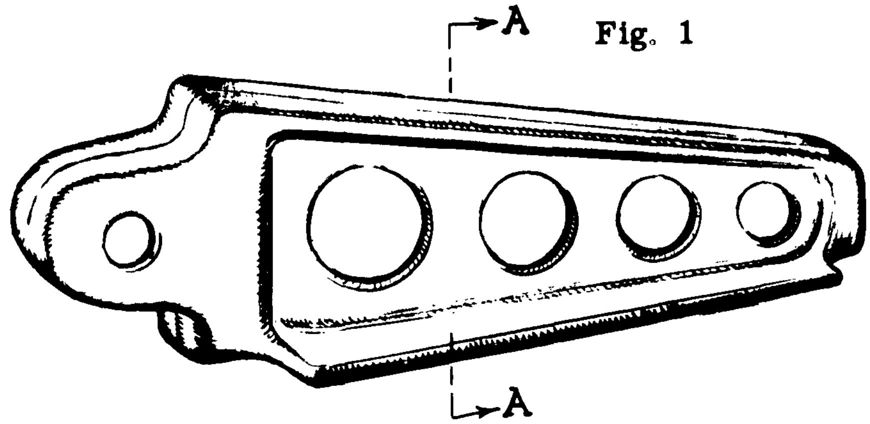
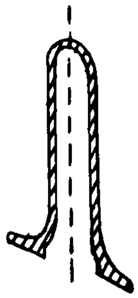


Fig. 1

ORIGINAL ALLOY STEEL FORGING
CHASE DRAG LINK FITTING
Chase Dwg. No. 8 B 310307



Section B-B

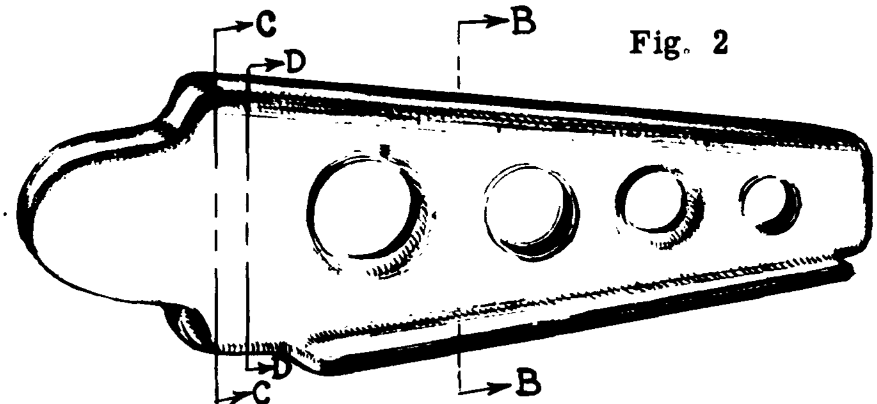


Fig. 2

Redesigned for Casting
DWG. No. CP-518

Section C-C

Fig. 2 shows Contractor's redesign of this part as a "tublar-form" steel casting with 1/8" wall section in main body. Superior strength-weight ratio of cast part is indicated by stress analysis and stress casting hereinafter reported.

Casting design was based on 150,000 psi ultimate. Sections cut from heat treated alloy steel casting, produced as physical form for stress test evaluation only, pulled at over 200,000 psi ultimate with 4 to 6% elongation, indicating substantial reduction in casting weight, as compared to forging, while retaining adequate strength, is attainable.

Section D-D

SECTION II - CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITT:
A. - DESIGN - (1) HISTORY OF DESIGN DEVELOPMENT

MATERIAL SELECTION: Calculations on the forged design (Section II-A-4, Stress Analysis by Chase) were based on a 4140 steel forging, heat treated to obtain a T. S. of 160,000 to 180,000 psi. Any reduction in material strength for the casting design would result in a reduced strength-weight ratio, particularly in the heavy lug section. Therefore, no reduction in tensile strength of the material should be considered in the redesign of this component. Rather, an increase in minimum tensile strength is recommended in order to achieve a higher strength-weight ratio.

In order to obtain the required tensile strength, a low alloy chromium - molybdenum steel would be selected. It should be normalized, quenched and drawn to obtain a minimum tensile strength of 180,000 psi, BHN 375-400.

STRUCTURAL SHAPE: Having established the critical design loads (from data supplied by aircraft manufacturer), and the above material specifications, the shape of the casting must now be considered. In consideration of casting shape, comprehensive evaluation of integrated thermal physical and mechanical factors of casting process must be scientifically applied in direct relation to the specific form considered, concurrently and inextricably with scientific stress evaluation. (This is mandatory in any reasonable approach to logical casting design development.

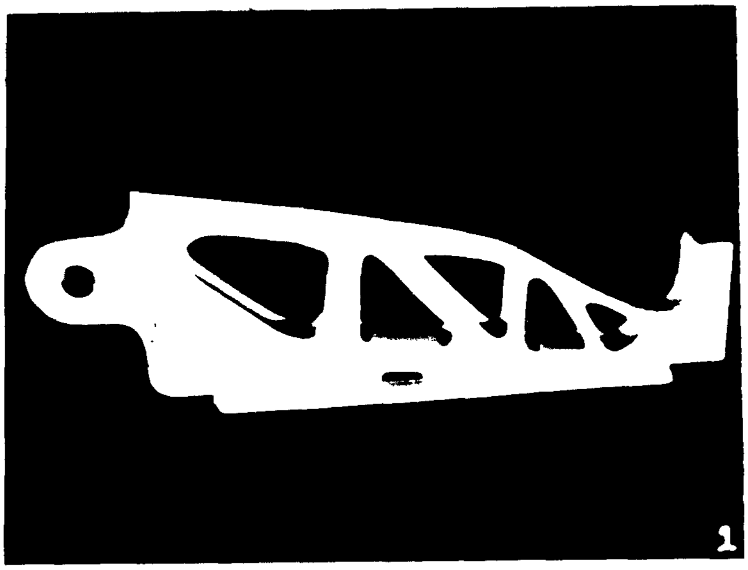
A "tublarform" casting was selected as the best structural shape to resist the combined loads of shear, simple tension and vertical and transverse bending. This form provided an approach to optimum uniformity and gradation of metal section, controlled thermal-path and uniformity of metal structure.

A sketch of the proposed design was made, Fig. 1, Stress Calculations, Section II-A-5) were made at various sections and were based on 1/8" typical wall section. Alternate holes were tied through in order to prevent local crippling of the thin wall due to shear and transverse bending.

The heavy section at the lug end presented no serious casting problem, since it occurred at only one point in the casting and thus could be "fed" separately from the gating system without compromising structure by running excess metal through the casting. A hydraulic flow analysis of the mold cavity and feeding system was made as a part of the Casting-Design-Process study.

MODELS EMPLOYED:

Full scale models were constructed in various stages of design development to establish shape and sectional transition. Models are made in desired scale from cardboard, wood, plastics, clay, etc. Fired clay ceramic models, as developed by Contractor, have advantages of strength and finish. Design changes are simply made. Numbers can be produced from easily altered plaster molds. Models can be sectioned. Models are considered mandatory in Casting-Design-Process Engineering for design and attachment visualization, pattern layout, pouring and gating. (Models illustrated on following pages.)



Models employed for design study are shown in successive development in Photos #1, 2, 3 and 4.

Photo #1: Cardboard model of "hat" section open web truss beam. Abandoned after study.

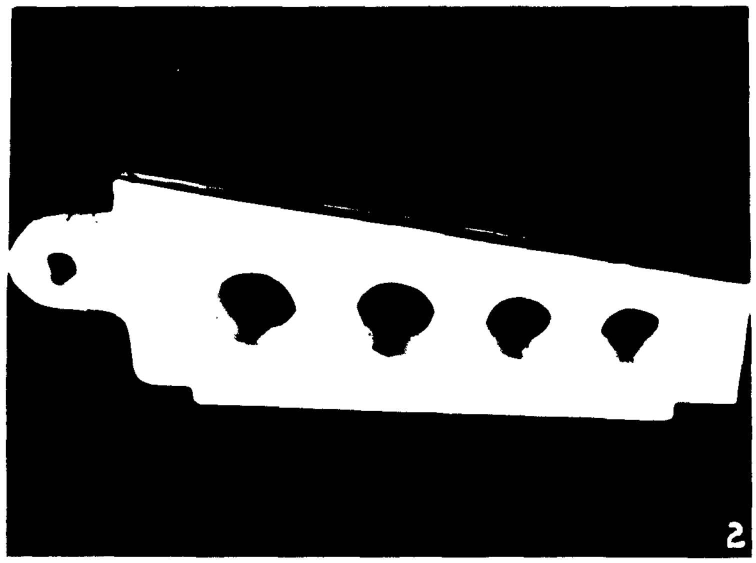


Photo #2: Composite paper-clay model with "holes" formed by tubular through-ties. This general type of "tublarform" box beam has been extensively employed by Contractor in alloy castings subject to shock and resultant high stresses. Objective is maximum possible uniformity of section.

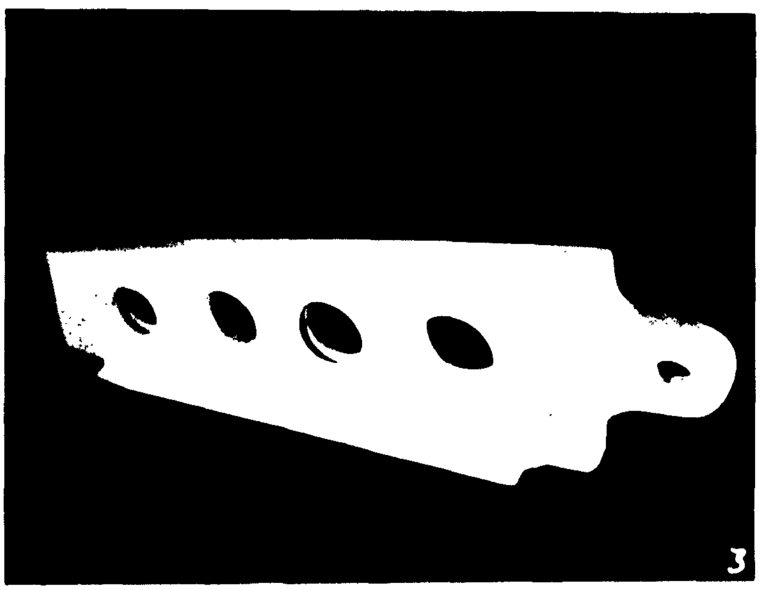
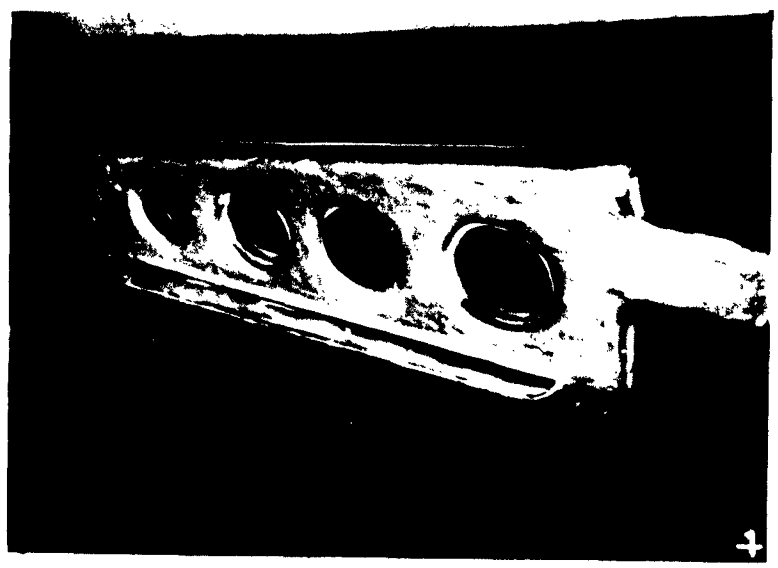


Photo #3: One of several ceramic models showing approximate design configuration made for study by staff and consultants. Ceramic models can be readily sectioned "green" with knife, or, when fired, cut-off wheel to reveal sections at desired points.

Ceramic models employed in Contractor's casting design-process study techniques are quickly and cheaply produced from plaster molds shown in Photos #3A and 3B. Plaster molds are produced from original models made in modeling clay, plastics or any other molding material.

Solidification of the ceramic casting is approximately comparable to the solidification of metal castings as heat is absorbed by the mold. Surface-to-mass ratios determine rate and gradient of solidification and "authority" of initially solidified "strong" sections over later solidified "weak" sections.

Photo #4: Final scale model, from detail drawing, of contoured clay on sheet plastic base is metal-coated. This model employed for final design study and for pattern and core box design in gating studies.



SECTION II

A-2. PHILOSOPHY of TUBLARFORM CASTING DESIGN and FATIGUE LIFE EXPERIENCE
(Including related physical and design considerations)

"Tublarform" design, as originally developed by Contractor, reflects cumulative experience in casting design-process technology directed at improvement of properties and particularly, fatigue life of heat resistant alloy castings subjected to uniquely destructive short cycle thermal stresses. Project Director established in 1928 that fatigue life in such as-cast castings is inversely proportional to grain size (*1). On the basis of extensive subsequent R&D in various cast metals this is considered to apply in general and in varying degree, to cast metals employable in aircraft.

"Grain size" and orientation of structure in castings is determined by rate of metal solidification. Metals in thin cast sections, poured at the same temperature in the same mold material will solidify faster, have finer structure, and, in general superior elongation and fatigue resistance, as compared to thicker sections.

Heat Treatment: In cast metals which can be materially altered in structure by heat treatment, the as-cast structure is of importance in relation to its contribution to - or limitation of - optimum properties attainable in a form for a specific use. It is noted, however, that the same factors of surface-to-mass ratios, which control cooling rate and determine the structure of castings, directly control relative cooling rate thus control metal structure, (insofar as structure is determined by cooling rate) - produced by heat treatment.

Residual Stresses: In both heating and cooling surface-mass relationship controls temperature change in a given configuration, in direct proportion to local sectional variations and relative conductivity. Local and total forces, induced by temperature related movement, - (i.e. expansion and contraction, in fluid, plastic and "solid" states), - their conflict, and extraneous impedances, produce dimensional change and residual stresses complexly interrelated. Residual stresses are a normal expectancy in castings and forgings and are predictable in relation to understanding and control. In some cases they may be beneficially employed as, for example, in cast tri-laminar structures. Stresses residual from casting are "relieved" in some materials to the extent that the strength of the metal in which they are confined is reduced by temperature to permit them freedom of movement

NOTE: *1. Heat resistant and most corrosion resistant alloys and many non-ferrous alloys are not subject to grain refinement by conventional heat treatment.

to effect proportional dimensional change. Equipment and process inequalities of heat input and extraction in process normally employed in foundries and forge shops inject variations (which are in need of understanding and improvement) and are as productive of residual stresses as the casting and forging processes. Thus stress removal is, in general, more hoped for than accomplished. From the foregoing it is apparent that design is a major controlling factor in test-indicated physical properties and, more important, in determining the overall load carrying properties and fatigue resistance of cast structures (*2).

SECTIONAL UNIFORMITY:

An ideal form, to obtain maximum physical properties, uniformity, fatigue resistance, machineability (and corrosion resistance in C. R. S. alloys) from advanced casting and heat treating process, would be of uniform section.

The full employment of uniform section is often difficult, or impossible, of attainment to meet functional requirements of design. Where compromise is indicated, the most uniform possible gradation from thick-to-thin section should be employed and all sharp changes in mass, and in direction, should be avoided. Thought and ingenuity devoted to minimize section and all sectional gradients, will be many times repaid by the suprior strength, physical uniformity and fatigue resistance of the casting.

DESIGNED-IN LIMITATIONS:

Radical sectional and directional variations in cast metal masses are "designed-in" limitations to strength, load distribution and service expectancy in castings. EXAMPLES: "Knee braces", in general, provide highly local and vastly inferior "stiffeners", as compared to cast contours. They are "stress-raisers" and have other shortcomings in structural design. In casting, "knee braces" and projecting "stiffeners" act as "cooling fins" which: (a) solidify quicker than the adjacent metal sections, (b) accelerate local shrinkage, and (c) impede contraction of the metal in the mold, - resulting in an inferior casting with increased residual stress. "Knee braces" contribute to deformation and/or residual stress in forgings, castings, or fabrications subjected to heat treatment. "I"-beam sections are grossly ill-adapted to casting. Principal reasons are: A two or three-to-one increase in mass over surface area occurs at intersections of web-and-flanges and insures that this area of metal remains fluid and/or plastic after the adjacent metal sections have solidified and "shrunk". In its subsequent solidification and contraction, thinner connecting areas are placed in compression, with the late-cooling metal in tension (*3). Such "shrinkage" is normally "fed" by adding large sections of metal ("heads") extraneous to the casting form, internal shrinkage is a normal expectancy. Such masses ("heads") locally delay cooling, create grossly large local structures, impede contraction, and have other disadvantages.

NOTES: *2. Preparation of Casting Design-Process Manual is recommended, Section V.

*3. Magnitude of relative forces is indicated by approx. metal shrinkage of 1/4" per linear foot and example of "hot" section contracting 1" on "cold" section in 4 ft. "I" beam.

Section II - A-2(continued)

"TUBLARFORMS" INDICATED:

"Tublarform", cored, casting design provides, in many applications, an optimum combination of:

a. Thinnest metal section permitted by load, and casting process (*4).

b. Attainable sectional uniformity and continuity of metal.

c. Possible elimination of corners, edges and terminal areas which induce heat transfer irregularities, "stress-raisers" and "notch-effects".

d. Maximum control of structure, thus assuring maximum application advanced casting and heat treating technology.

Entirely apart from the casting design-process advantages of "tublarform" sections, the strength-weight superiority, inherent in tubing, has long been employed in aircraft and in many highly efficient structures. The possibility of employing the advantages associated with "stressed skin" in the "tublarforms" of aircraft fuselage sections, with the basic form-strength-weight advantages of "tublarform" design, becomes apparent.

Castings, in varying degree, - in different metals and sections, - are "trilaminar" structures, the section roughly resembling a carburized section with a "case" and a "core". The outer cast surface, first chilled by the mold, solidifies as an "envelope" surrounding the fluid "core" metal which, subsequently, contracts, placing the enveloping "skin" in compression and the "core" in tension. In specific metals and forms, employing specific casting techniques, such trilaminar structures can be controlled, as can basic metal structures with "columnar" or other types of grain orientation controlled by process, and disposed locally with benefit.

Where load, and/or method of attachment, - (designed for component produced by other process) dictates radically increased masses adjacent to thin sections, the "tublarform" provides superior stress distribution in juncture of thin and thick sections.

Ingenuity has been applied in tying in "tublarforms" by such "donut" tie-thrus, as employed on subject component and in a variety of more complex configurations.

DESIGN LATITUDE AVAILABLE:

A variety of cored tubular and "envelope" forms, "U" sections, "hat" sections, "S" and "Z" sections and corrugated, "dimpled", spot-crowned and contour-

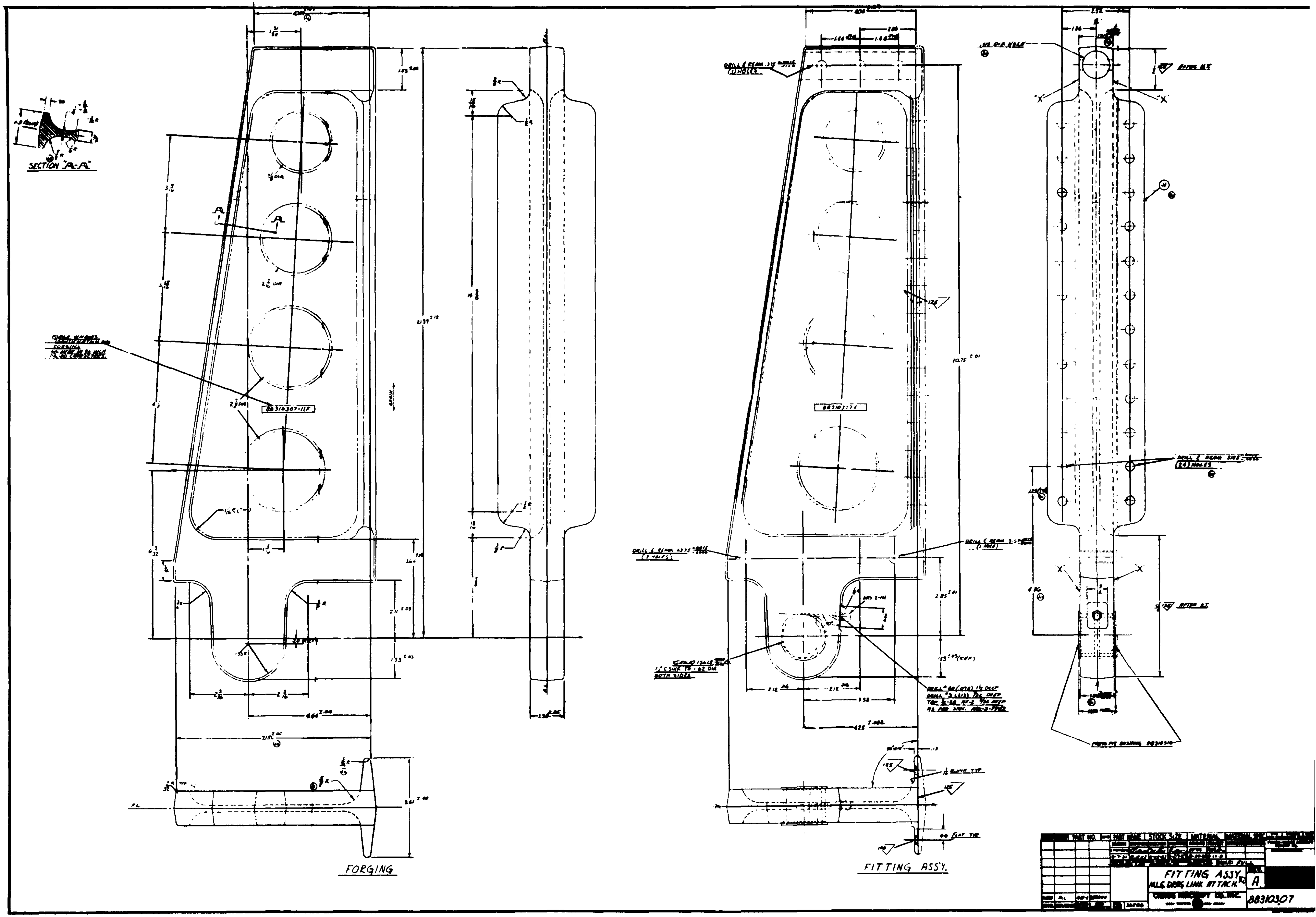
NOTE *4. Sections far thinner than generally considered "castable" by conventional process are attainable by advanced casting process. Oxide film, "surface-tension" and "wetting-effect", not metal "fluidity" limit metal sections, are effectively controllable, in various degree, in advanced process employing non-organic molds.

strengthened forms have been designed and cast by Contractor over many years. They have been proven to be advantageous in improvement of cast structures resulting in greatly increased load carrying ability, and service-life (as compared to angular "re-inforced" designs in thicker metal sections).

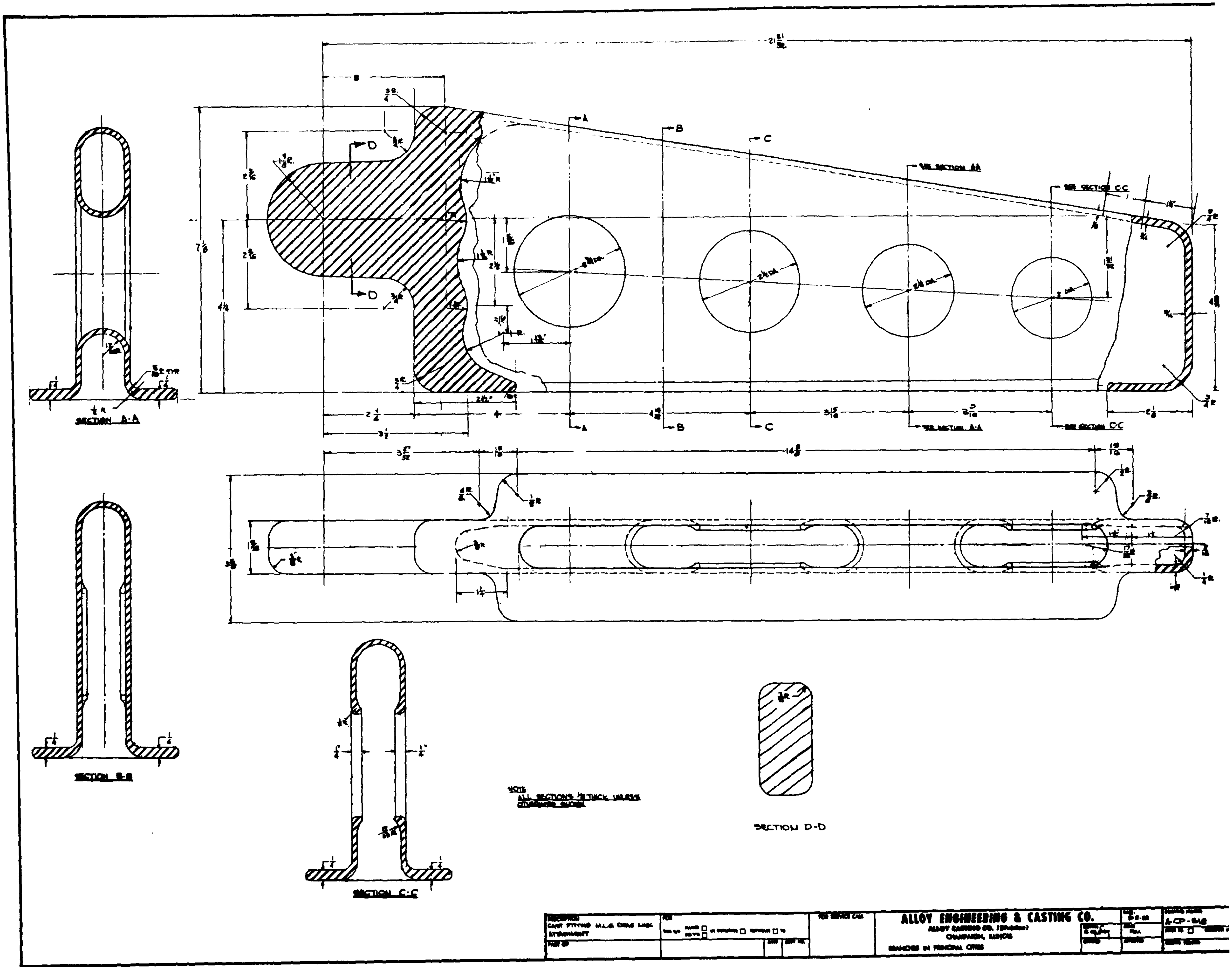
COMMENT:

It will be found that Contractor's design-process philosophy offers as many advantages in improving strength-weight ratios of aircraft components. Such forms have not been generally utilized because. (a) they are difficult of impossible of attainment by forging, and (b) they necessitate higher tooling costs in small production by fabrication. They are readily producible as castings, preferably in non-organic molds, by advanced processes.

It is believed that physical stress testing of castings designed and produced with maximum, currently possible, utilization of casting design-process technology should provide confirmation of Contractor's casting design-process philosophy as applied to production of aircraft components by advanced process.



CHASE AIRCRAFT COMPANY, INC. C-123B, MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
PART NO. 8B-310307-1. Dwg. NO. 8B310307.
MATERIAL: STEEL FORGING



CHASE C-123B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
REDESIGNED AS "TUBLARFORM" HIGH-STRENGTH STEEL CASTING. A.E.C.CO. Dwg. NO. CP-518
REDESIGNED FROM CHASE PART NO. 8B-310307-1, Dwg. NO.8B310307, STEEL FORGING

STRESS ANALYSIS

BY

CHASE AIRCRAFT COMPANY, INC.

OF

MAIN GEAR SUPPORT STRUCTURE

DRAG LINK ATTACHMENT FITTING

PART NO. 8B-310307

ENGINEERING STUDY

OF

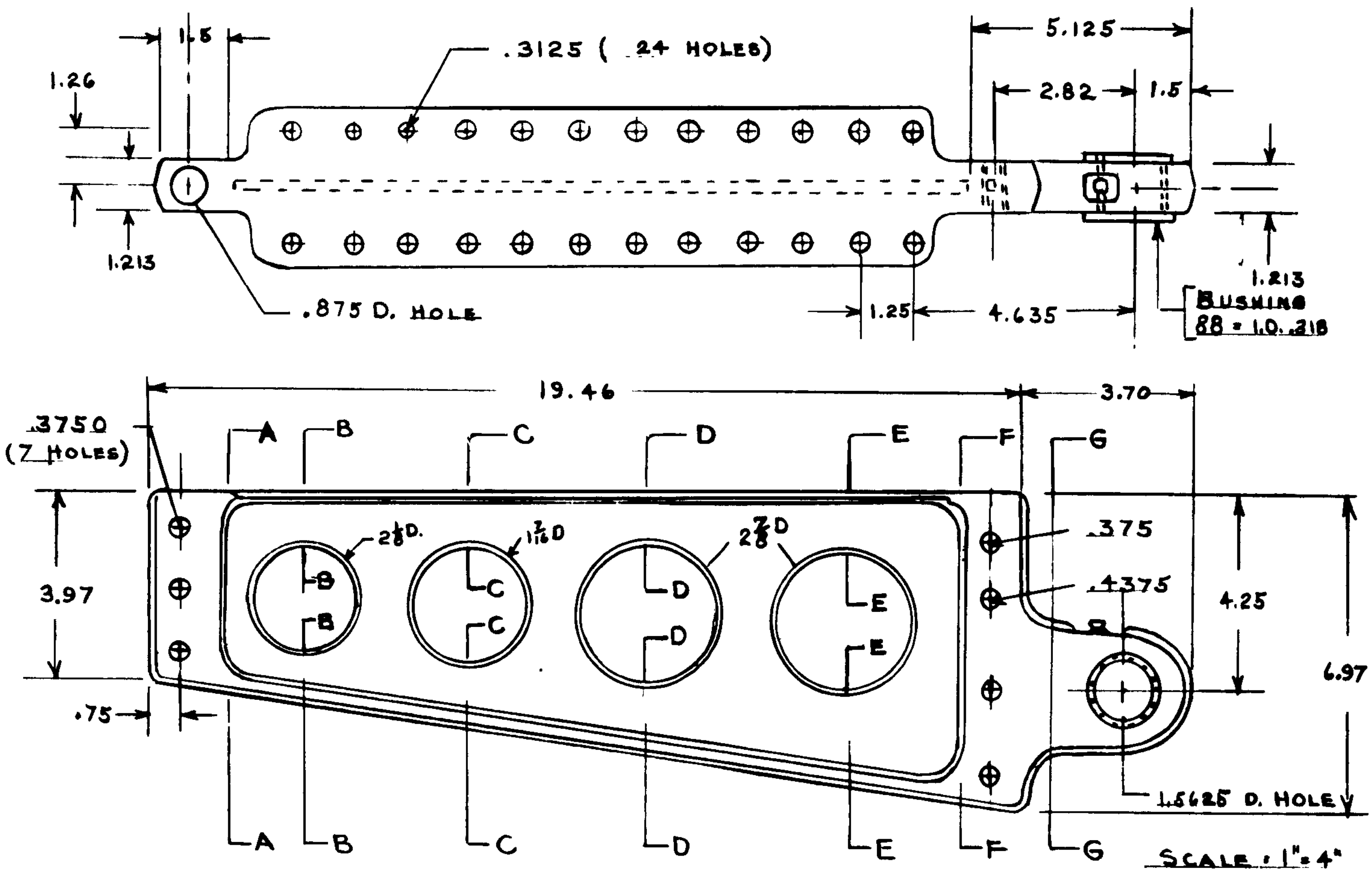
FORGING

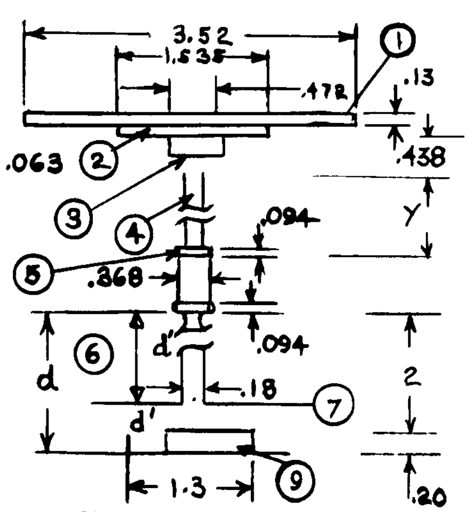
CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 11-26-51
CHKD. P.B.K. ON 12-5-51
REVISED

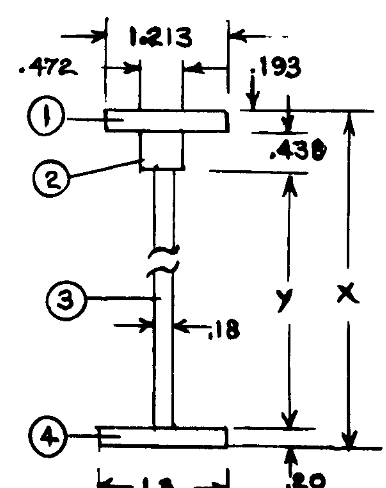
PAGE 1
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING





NOTE:
DRAFT ANGLES
ROUNDS & FILLETS
CONSERVATIVELY
OMITTED.



TYPICAL SECTION
FOR
A-A, F-F

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 12-4-51 PG. 2
CHKD. P.B.K. REPORT NO.
REVISED MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SECTION A-A X= 4.500 IN Y= 3.669 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^1	ΣAd^1
1	.193x1.213	.234	4.404	1.031	2.019	.472	.953	.472
2	.438x.472	.207	4.088	.846	1.703	.353	.601	.825
3	.180x3.669	.660	2.035	1.343	-.350	-.231	.081	.594
4	.200x1.300	.260	.100	.026	-2.285	-.544	1.357	0
Σ		1.361		3.246		2.992		

$\bar{d} = \frac{3.246}{1.361} = 2.385$ IN

$I = 2.992$ IN^4

$A = 1.361$ IN^2

SECTION B-B X = 4.625 IN Y=.500 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
1	.130x3.520	.458	4.560	2.088	.218	.100	.022	.100
2	.063x1.535	.097	4.464	.433	.122	.012	.001	.112
3	.438x.472	.207	4.213	.872	-.129	-.027	.003	.085
4	.180x.500	.090	3.744	.337	-.598	-.054	.032	.031
5	.094x.368	.035	3.447	.121	-.895	-.031	.028	0
Σ		.887		5.851			.086	

$\bar{d} = \frac{3.851}{.889} = 4.342$ IN

$I = .086$ IN^4

$A = .887$ IN^2

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 12-4-51
CHKD. P.B.K. ON 12-5-51
REVISED

PAGE 3
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SECTION B^1B^1 X = 4.625 IN Z = .981 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
6	.094x .368	.035	1.228	.043	.823	.029	.024	.029
7	.180x .981	.177	.691	.122	.286	.051	.015	.080
8	.200x1.300	.260	.100	.026	-.305	-.079	.024	0
Σ		.472		.191			.063	

$\bar{d}^1 = \frac{.191}{.472} = .405$ IN

I = .063 IN^4

A = .472 IN^2

$\bar{d} - \bar{D}^1 = 4.342 - .405 = 3.937$ IN

SECTION C-C X = 5.200 IN Y = .525 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	Ad^1
1	.130x3.520	.458	5.135	2.352	.224	.103	.023	.103
2	.063x1.535	.097	5.039	.489	.128	.012	.002	.115
3	.438x .472	.207	4.788	.991	-.123	-.025	.003	.090
4	.180x .525	.095	4.307	.409	-.604	-.057	.034	.033
5	.094x .368	.035	3.997	.140	-.914	-.032	.029	0
Σ		.892		4.381			.091	

$\bar{d} = \frac{4.381}{.892} = 4.911$ IN

I = .091 IN^4

A = .892 IN^2

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 12-4-51
CHKD. P.B.K. ON 12-5-51
REVISED

PAGE 4
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SECTION C^1-C^1 X = 5.200 IN Z = 1.206 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
6	.094x.368	.035	1.453	.051	.963	.034	.033	.034
7	.180x1.206	.217	.803	.174	.313	.068	.021	.012
8	.200x1.300	.260	.100	.026	-.390	-.101	.039	0
Σ		.512		.251			.093	

$\bar{d}^1 = \frac{.251}{.512} = .490$ IN

$I = .093$ IN^4

$A = .512$ IN^2

$\bar{d} - \bar{d}^1 = 4.911 - .490 = 4.421$ IN

SECTION D-D X = 5.850 IN Y = .465 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
1	.130x3.520	.458	5.785	2.650	.222	.102	.023	.102
2	.063x1.535	.097	5.689	.552	.126	.012	.002	.114
3	.438x.472	.207	5.438	1.126	-.125	-.026	.003	.088
4	.180x.525	.095	4.956	.471	-.607	-.058	.035	.030
5	.094x.368	.035	4.647	.163	-.916	-.032	.029	0
Σ		.892		4.962			.092	

$\bar{d} = \frac{4.912}{.892} = 5.513$ IN

$I = .092$ IN^4

$A = .892$ IN^2

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 12-4-51
CHKD. P.B.K. ON 12-5-51
REVISED ______

PAGE 5
REPORT NO. ____
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SECTION D^1-D^1 X = 5.850 IN ~~Z~~ = 1.406 IN.

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
6	.094x.368	.035	1.653	.058	1.084	.038	.041	.038
7	.180x1.406	.253	.903	.228	.334	.085	.028	.123
8	.200x1.300	.260	.100	.026	-.469	-.122	.057	0
Σ		.548		.312			.126	

$\bar{d} = \frac{.312}{.548} = .569$ IN

I = .126 IN^4

A = .548 IN^2

$\bar{d} - \bar{d}^1 = 5.563 - .569 = 4.994$ IN

SECTION E-E X = 6.550 IN Y = .775 IN

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
1	.130x3.520	.458	6.485	2.970	.281	.129	.036	.129
2	.063x1.535	.097	6.389	.620	.185	.018	.003	.147
3	.438x.472	.207	6.138	1.271	-.066	-.014	.001	.133
4	.180x.775	.140	5.532	.774	-.672	-.094	.063	.039
5	.094x.368	.035	5.097	.178	-1.107	-.039	.043	0
Σ		.937		5.813			.146	

$\bar{d} = \frac{5.813}{.937} = 6.204$ IN

I = .146 IN^4

A = .937 IN^2

CHASE AIRCRAFT COMPANY, INC.

PREP. J. PIROLA ON 12-4-51
CHKD. P.B.K. ON 12-5-51
REVISED

PAGE 6
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SECTION $E^1 - E^1$ X = 6.550 IN ~~Z~~ = 1.881 IN.

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
6	.094x.368	.035	2.218	.074	1.360	.048	.065	.048
7	.180x1.881	.339	1.141	.387	.373	.126	.047	.174
8	.200x1.300	.260	.100	.026	-.668	-.174	.116	0
Σ		.634		.487			.228	

$\bar{d} = \frac{.487}{.634} = .768$ IN

I = .228 IN^4

A = .634 IN^2

$\bar{d} - \bar{d}^1 = 6.204 - .768 = 5.436$ IN.

SECTION F-F X = 6.800 IN. Y = 5.969 In.

ITEM	DIMENSIONS	A	d	Ad	d^1	Ad^1	Ad^{12}	ΣAd^1
1	.193x1.213	.234	6.704	1.569	3.133	.733	2.296	.733
2	.438x.472	.207	6.388	1.322	2.817	.583	1.642	1.316
3	.180x5.969	1.074	3.185	3.421	-.386	-.415	.160	.901
4	.200x1.300	.260	.100	.026	-3.471	-.902	3.131	0
Σ		1.775		6.338			7.229	

$\bar{d} = \frac{6.338}{1.775} = 3.571$ IN

I = 7.229 IN^4

A = 1.775 IN^2

SECTION G-G

DIMENSIONS = 1.213 x 2.850

AREA = 3.457 IN^2

$I_{xx} = \frac{1.213(2.850)^3}{12} = 2.340$ IN^4

$\bar{y} = 1.425$ IN Ad = 4.926

$I_{yy} = \frac{2.850(1.213)^3}{12} = .424$ IN^4

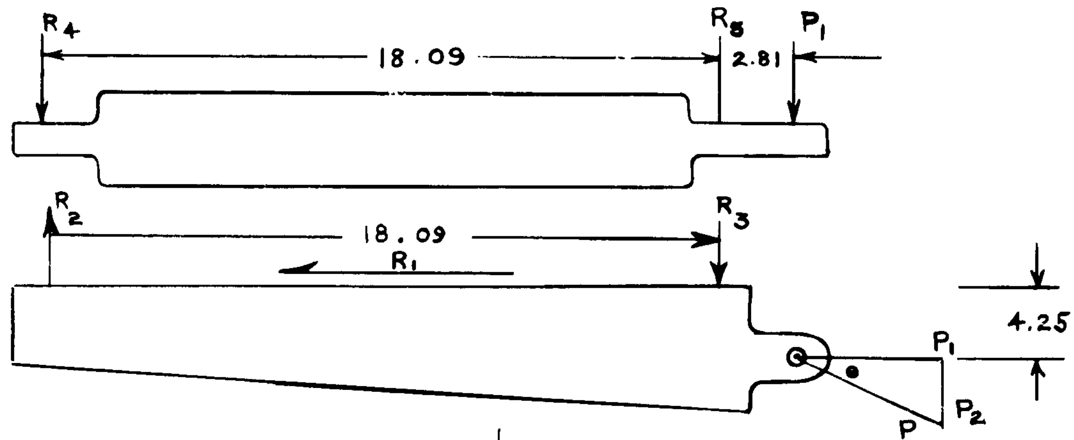
$\bar{X} = .607$ IN.

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

PREP. J. PIROLA ON 12-12-51
CHKD. L.L.M. ON 12-17-51
REVISED

PAGE 7
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING



OUTBOARD FITTING R.H.S.

Static Condition

$P(\text{Tension}) = 121{,}700\#$

$\theta = 11^\circ\ 12'$

$P_y = \frac{48950}{2} = 24{,}475\ \#$

$P_1 = P \cos\theta = 121{,}700(.9810)$

$P_1 = 119{,}390\#$

$P_2 = P \sin\theta = 121{,}700\ (.1942)$

$P_2 - 23{,}630\#$

$R_1 = P_1 = 119{,}390\#$

$R_2 = \frac{4.25\ P_1 - 2.82\ P_2}{18.09} = \frac{440771}{18.09}$

$R_2 = 24{,}365\#$

$R_3 = \frac{4.25\ P_1 - 20.91 P_2}{18.09} = \frac{13305}{18.09}$

$R_3 = 735\#$

$R_4 = \frac{2.82}{18.09}\ P_y = .1559(24475)$

$R_4 = 3{,}816\#$

$R_5 = \frac{20.91}{18.09}\ P_y - 1.1559\ (24475)$

$R_5 = 28{,}290\#$

Extended Condition

$P\ (\text{Tension}) = 117{,}140\#$

$\theta = 24^\circ\ 48'$

$P_y = \frac{46650}{2} = 23{,}325\#$

$P_1 = P \cos\theta = 117140(.9078)$

$P_1 = 106{,}340\#$

$P_2 = P \sin\theta = 117140(.4195)$

$P_2 = 49{,}140\#$

$R_1 = P_1 = 106{,}340\#$

$R_2 = \frac{4.25 P_1 - 2.82\ P_2}{18.09} = \frac{313370}{18.09}$

$R_2 = 17{,}323\#$

$R_3 = \frac{4.25\ P_1}{18.09} - 20.91\ P_2 = \frac{-575572}{18.09}$

$R_3 = -31{,}817\#$

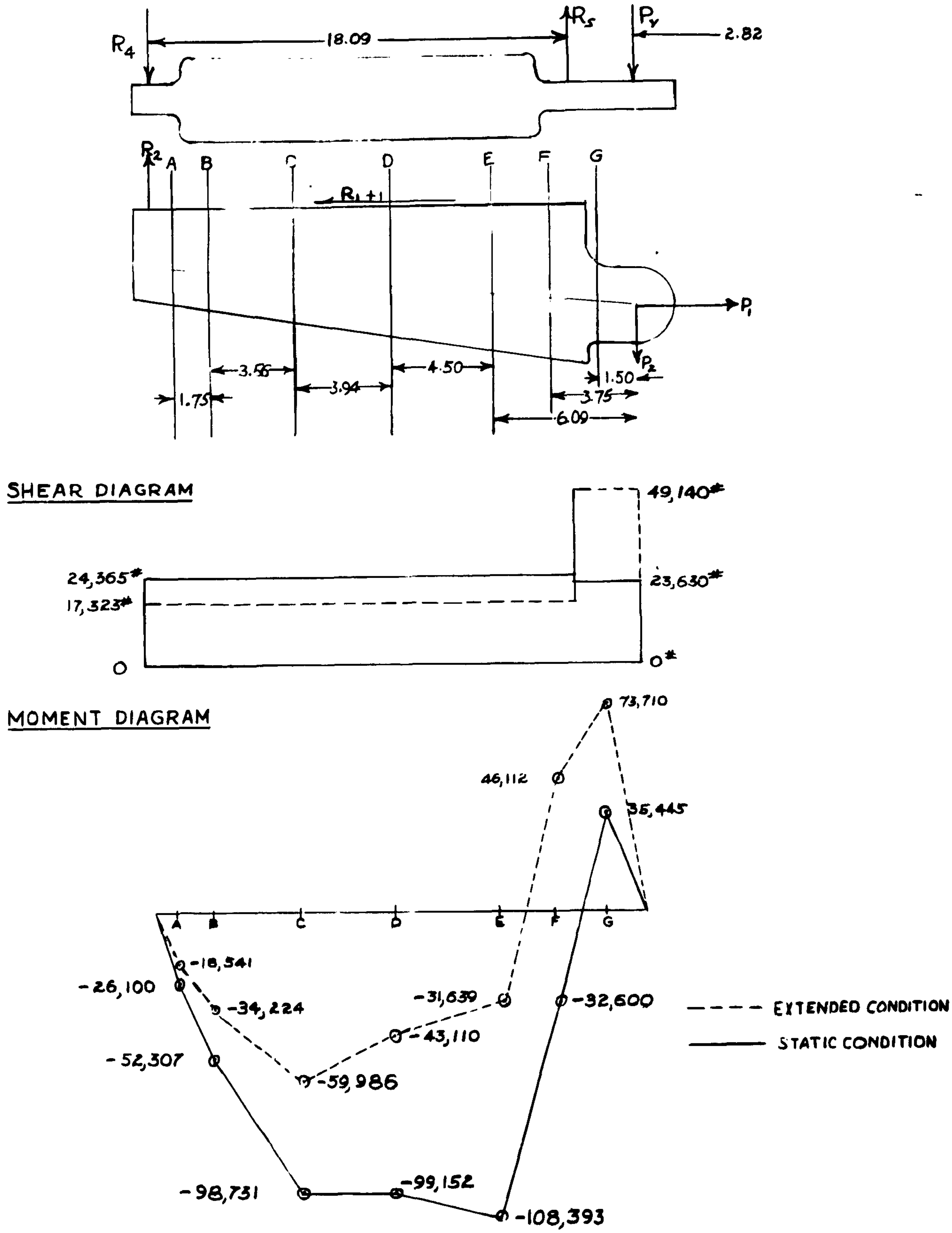
$R_4 = \frac{2.82}{18.09} P_y = .1559(23{,}325)$

$R_4 = 3{,}636\#$

$R_5 = \frac{20.91}{18.09} P_y = 1.1559(23{,}325)$

$R_5 = 26{,}960\#$

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING



THE FOLLOWING TWO PAGES

CONTAIN

TABULATION OF STRESS ANALYSIS

BY

SECTIONS

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N.J.

PREP. J. PIROLA ON 12-4-51
CHKD. P.B.K. ON 12-5-51
REVISED

PAGE 9A
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

1	2	3	4	5	6	7	8	9	10
SECTION	M	d	P	P-N P_B	Ia (L)	Iu +IL	Iu(L) Iu+IL	Pu(L)	A
REF			2 ± 3				6 / 7	4 + 5 x 8	
A-A	-26100	---	---	0	2.992	---	1	0	1.361
B-B			-13290		.086		.577	-7560	.887
	-52310	3 937		9940		.149			
B^1-B^1			13290		.063		.423	17500	.472
C-C			-22330		.091		.495	-2630	.892
	-98730	4.421		39790		.184			
C^1-C^1			22330		.093		.505	4.2420	.512
D-D			-19850		.092		.422	9540	.892
	-99150	4.994		69640		.218			
D^1-D^1			19850		.126		.578	60,100	.548
E-E			-19,940		.146		.390	18,860	.937
	-108,390	5.436		99,490		.374			
E^1-E^1			19,940		.228		.610	80629	.634
F-F	46,112	----	-----	106340	7229		1	106340	1.775
G-G	73,710	----	-----	106340	2340		1	106340	3.457

$*f = \frac{MC}{I} + \frac{P^1}{A}$ MAXIMUM VALUE SHOWN IN TABLE

A-A - $f_b = \frac{-26100(-2.385) + 0}{2.992} = +20805$ psi

$f_t = \frac{-26100(2.115) + 0}{2.992} = -18453$ psi

F-F $f_b = \frac{46112(-3.571)}{7.229} + \frac{106340}{1.775} = 37122$ psi

$f_t = \frac{46112(3.229)}{7.229} + \frac{106340}{1.775} = 80513$ psi

CHASE AIRCRAFT COMPANY, INC.
WEST TRENTON, N. J.

CHKD. L. L. M. ON 12-29-51
PREP. J. PIROLA ON 12-17-51
REVISED

PAGE 9B
REPORT NO.
MODEL MS

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

11	12	13	14	15	16	17	18	19	20
f	Fall	M S	V	Vu (L)	Q	$\frac{VQ}{I}$ = S	fs	M.S.	M
$\frac{9}{10}$		$\frac{12}{11}$ - 1		8x14		$\frac{15 \times 16}{6}$	17/t	$\frac{\text{Fall**}}{18}$ - 1	-1
20810	160000	LARGE	24365	24365	.825	6718	37320	AMPLE	
-8,520		LARGE		14059	.085	13890	77170	.23	
37,080		LARGE		10306	.080	13079	72660	.31	
-2950		LARGE		12061	.090	11928	66270	.43	
82,850	160,000	.93		12304	.102	13495	74970	.27	
10,700	128,000	LARGE		10282	.088	9840	54670	.74	
109,670	160,000	.46		14083	.123	13746	76370	.24	
20,130	128,000	LARGE		9502	.133	8660	48110	.97	
127,480	160,000	.26		14863	.174	11342	63010	.51	
80510*	160,000	.99	24365	24365	1.316	4435	24640	LARGE	
75650*	160000	AMPLE	49140	49140	1.232	25870	21330	LARGE	

G-G= $f_b = \frac{73710(-1.425)}{2.340} + \frac{106540}{3.457} = -14129$ psi

$f_t = \frac{73710(+1.425)}{2.340} + \frac{106340}{3.457} = 75649$ psi

** Fall In Shear = 95000 psi

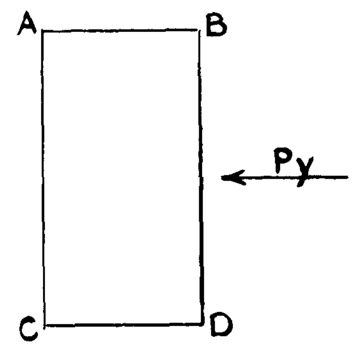
CHASE AIRCRAFT COMPANY, INC.

PREP. J. PIROLA ON 12-17-51
CHKD. L.L.M. ON 12-28-51
REVISED

PAGE 10
REPORT NO.
MODEL C-123B MS 8B-

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

Check of Section G-G —



$$f = \frac{M_x C_x}{I_{xx}} + \frac{M_y C_y}{I_{yy}} + \frac{P}{A}$$

$$f_d = \frac{73710\,(-1.425)}{2.340} + \frac{\left(\frac{466.50}{2}\right)(.607)}{.424} + \frac{106340}{3.457}$$

$$f_d = -44889 + 33400 + 30760$$

$$\underline{f_d = 19270 \text{ psi}}$$

$$f_c = -44889 - 33400 + 30760$$

$$\underline{f_c = -47530 \text{ psi}}$$

$$f_b = 44889 + 33400 + 30760$$

$$\underline{f_b = 109050 \text{ psi}} \qquad M.S. = \frac{160000}{109050} - 1 = .47$$

$$f_a = 44889 - 33400 + 30760$$

$$\underline{f_a = 42250 \text{ psi}}$$

SUBJECT MAIN GEAR SUPPORT STRUCTURE
DRAG LINK ATTACHMENT FITTING

SHEAR OUT OF FITTING ---

$P_s = 2 \times tf_s \qquad f_s = \frac{P_s}{2 \times t}$

$f_s = \frac{121700}{2(.80)(1.213)} = 62700$ psi

$M.S. = \frac{95000}{62700} - 1 = .52$

TENSION THROUGH HOLE ---

$P_t = (2R-D)tf_t \qquad f_t = \frac{P_t}{(2R-D)t}$

$f_t = \frac{121700}{\left[(2.7)-1.5625\right]1.213} = 88208$ psi

$M.S. = \frac{160000}{88200} - 1 = .82$

BEARING OF BUSHING ON FITTING ----

$P_{br} = Dtf_{br} \qquad f_{br} = \frac{P_{br}}{Dt}$

$f_{br} = \frac{121700}{1.5625(1.213)} = 64220$ psi

$M.S. = \frac{193300}{2^*(64220)} - 1 = .50$

BEARING OF BOLT ON BUSHING ----

$P_{br} = Dtf_{br} \qquad f_{br} = \frac{P_{br}}{Dt}$

$f_{br} = \frac{121700}{1.3125(1.213)} = 76440$ psi

$M.S. = \frac{193300}{2^*(76440)} - 1 = .26$

* BEARING FACTOR, REF.

STRESS ANALYSIS

by

CONTRACTOR

of

CONTRACTOR'S REDESIGN

of

CHASE C-123-B MAIN LANDING GEAR
DRAG LINK ATTACHMENT FITTING

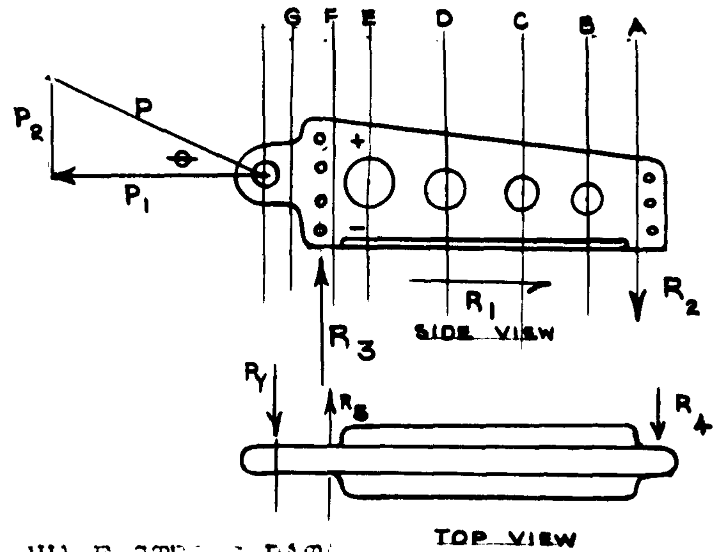
CHASE PART NO. 8B-310307, Dwg. #8B-310307
(A. E. C. Co. Dwg. #CP-518)

NOTE: Component is redesigned from "I" Section Steel Forging to "Tublarform" High Strength Steel Casting. Design based on 150,000 psi ultimate. (Test of samples cut from section of heat-treated Alloy Steel Casting indicate 200,000 psi ultimate.)

ALLOY ENGINEERING & CASTING COMPANY
Champaign, Illinois

CHASE DRAG LINK

DESIGN CALCULATIONS



LOADS AS TAKEN FROM CHASE STRESS DATA

STATIC CONDITION

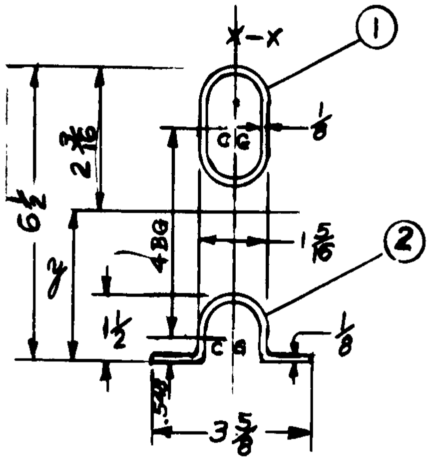
$P = 121,700$ #
$\theta = 11^\circ\ 12'$
$P_y = 24,475$ #
$P_1 = 119,390$ #
$P_2 = 23,630$ #
$R_1 = 119,390$ #
$R_2 = 24,365$ #
$R_3 = 735$ #
$R_4 = 3816$ #
$R_5 = 28,290$ #

EXTENDED CONDITION

$P = 117,140$ #
$\theta = 24^\circ\ 48'$
$P_y = 23,325$ #
$P_1 = 106,340$ #
$P_2 = 49,140$ #
$R_1 = 106,340$ #
$R_2 = 17,323$ #
$R_3 = -31,817$ #
$R_4 = 3636$ #
$R_5 = 26,960$ #

CP-561

SECTION-E VERTICAL BENDING



AREA (1) $= (1.35^{\cdot .49} - .86) + (.875^{\cdot .218} x .25) = .71 \text{ IN}^2$

AREA (2) $= (2.31^{\cdot .289} x .125) + (.24) + (1.37^{.71} - 66)$
$.25 = .70 \text{ IN}^2$

AREA (1) + (2) = 1.41 IN^2

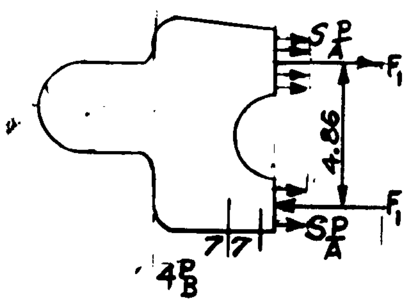
CG (1) = 6.5 - 1.09 = 5.41

CG (2) = $\frac{\Sigma AY}{\Sigma A} = \frac{(.24 \times 1.22) + (.178 \times .42) + (.289 \times .06)}{.70}$

$= \frac{.383}{.70} = .548$

CG(1) - CG(2) = 5.41 - .548 = 4.86

STATIC COND.



M = -108,393 IN#

P_1 = 119,390 #

P_b = LOAD TAKEN BY EACH BOLT = 4.970#

S_m = STRESS DUE TO MOMENT = $\frac{F_1}{A(1)} \frac{-22,300}{.71} = 31,400$ #

$F_1 = \frac{M}{4.86} = \frac{108,393}{4.86} = 22,300$ #

TOTAL $S_t = S_m + S_{p/a} = S_m + \frac{P_1 - np_b}{A(1) + (2)} = 31,400 + \frac{(119,390) - 4(4.970)}{1.41}$

S_t = 31,400 + 70,500 = 101,900 psi

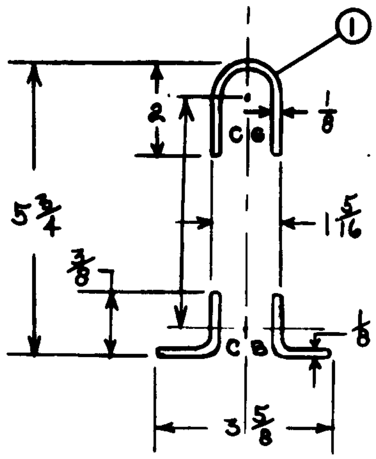
EXTENDED COND.

MOMENT IS OF SAME SIGN + LESS

$\frac{P_1 - np_b}{A(1) + A(2)}$ IS OF SAME SIGN + LESS

S_t = LESS

SECTION D VERTICAL BENDING



AREA (1) = $\frac{(1.35-.06)}{2} + 2(2 \times .050) .125 = .57 \text{ IN}^2$

AREA (2) = $(1.37 \times .125 \times .2) + (2.06 \times .125) = .60 \text{ IN}^2$

AREA (1) + (2) = 1.17 IN^2

CG(1) = $5.75 - \boxed{\frac{(.335 \times 1.32) + (.24 \times .39)}{.57}}$

$= 5.75 - .94 = 4.81$ IN

CG(2) = $\frac{(.342 \times .09) + (.257 \times .06)}{.60} = .42$ IN

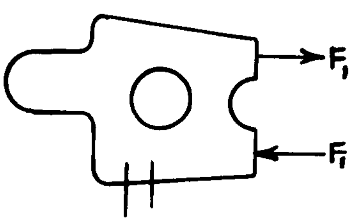
CG(1) - CG(2) = 4.81 - .42 = 4.39 IN.

STATIC CONDITION

M = 98,731 in#

P_1 = 119,390 #

P_B - LOAD PER BOLT = 4,970 #



S_M = STRESS DUE TO MOMENT $= \frac{F_1}{A(1)}$

$F_1 = \frac{M}{4.39} = \frac{98,731}{4.39} = 22,500$ #

$S_M = \frac{22,500}{.57} = 39,500$ #

TOTAL $S_T = S_M + \frac{S_D}{a} = S_n + \frac{P_1 - nP_B}{A_1 + A_2} = 39,500 + \boxed{\frac{119,390-10(4970)}{1.17}}$

S_T = 39,500 + 59,500 = 99,000 psi

EXTENDED CONDITION

S_T = LESS

CP-501

BEARING ON BOLTS AT R_2

STATIC CONDITION

R_2 = 24,365 #
D = DIA BOLT = .375 IN
N = NUMBER OF BOLTS = 3
S_B = STRESS IN BEARING
T = WALL THICKNESS = .125 IN
A = TOTAL BEARING AREA
A = D x 2N x T

$$A = .375 \times 6 \times .125 = .281 \ IN^2$$

$$S_B = \frac{24,365}{.281} = 86,700 \text{ psi}$$

EXTENDED CONDITION

R_2 = 17,323#
S_B = < 86,700 psi

SHEAR ON BOLTS AT R_2

STATIC CONDITION

R_2 = 24,365 #
D = DIA BOLT = .375 IN
N = NUMBER OF BOLTS = 3
S_S = STRESS IN SHEAR
A = TOTAL SHEAR AREA
= 2N .11 = .66 IN^2

$$S_S = \frac{24,365}{.66} = 36,900 \text{ psi}$$

EXTENDED CONDITION

R_2 = 17,323 #

S_S = < 36,900 psi

CP-561

SECTION II - CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING.

B. Experimental Production of Castings in Contractor's Normal Heat Resistant Alloys from Wooden Patterns in Sand Molds, to Provide Physical Forms for Stress Evaluation Only.

Twelve castings cast in sand molds made from rigging previously described, were produced in six pourings in 35% nickel - 15% chrome alloy (as specified). This is a standard analysis in Contractor's regular production, - used for convenience in producing castings for design evaluation only

In addition to these castings, two more castings in similar analysis and two high-strength alloy steel castings were produced with same pattern equipment by General Alloys Company, Boston which are reported on following pages. Minor variations in design were made by core alteration to follow progressive design modification. Minor changes in gating orifices ferrostatic pressure and volumetric changes in heads were progressively made, as were experiments to determine minimum pouring temperature necessary to run casting Several of these castings are illustrated on page following.

Final experimental alloy castings, which were machined in accordance with Chase drawings for testing on specially built hydraulic stress testing fixtures, were produced from patterns and rigging exactly as shown in preceding photo. No unusual difficulty was experienced in running the alloy castings at Contractor's normal low pouring temperatures. While pressure head was employed no pressure could be generated in the mold until head was filled

Proprietary ceramic gating produced in A.E.C.Co. Ceramic Department was employed. This insures material improvement in casting quality and cleanliness by eliminating steam, and sand erosion in gating system. Eroded "dirt", gas and steam (normally contaminating metal before entrance of mold in sand gating) is largely eliminated. Oxide formation in gating systems (which retards fluidity of metal and contaminates casting) is greatly reduced.

Minor sectional variations reflected normal wood pattern and sand registration irregularities. X-rays revealed minor porosity under gate sections in some castings, readily repairable by welding. This will be entirely eliminated from production castings.

High-strength alloy steels can be poured at lower temperatures and in thinner sections by (a) the projected employment of Contractor's ceramic molds (capable of withstanding materially higher pressures and free from the erosion, contamination of metal, and formation of oxides inherent in organic bonded molds, and (b) casting centripetally under controlled pressure.

Photographs clearly show the castability of light weight, thin section (1/8" or under) in configurations designed with casting design-process engineering cognizance.

B. Experimental Production of Castings in Contractor's Normal Heat Resistant Alloys from Wooden Patterns in Sand Molds, to Provide Physical Forms for Stress Evaluation Only.

1. Photographs of Mold, Pattern, Core Boxes and Ceramic Gating.

MOLD, PATTERN, CORE BOXES, CERAMIC GATING AND RIGGING employed in experimental sand casting (to provide physical forms in Ni.-Cr. H.R. Alloy for stress tests for design evaluation only).

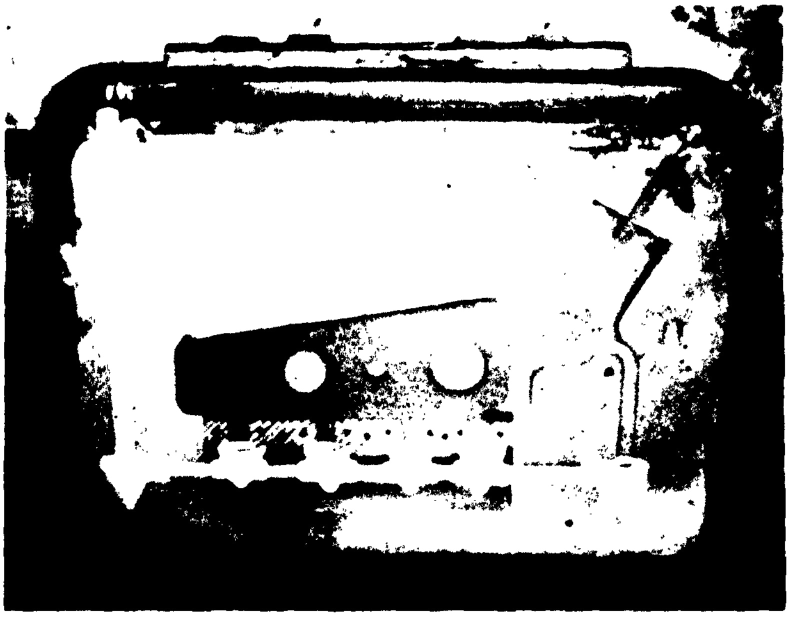


Photo #1: Shows half of vertically parted sand mold with proprietary ceramic gating located for illustrative purposes. (Runner gates and ingates to casting are incorporated in core in actual practice.) Mold is tilted to obtain desired flow and related thermal pattern of metal entering and filling mold through eight ingates connected in pairs to ceramic gating.

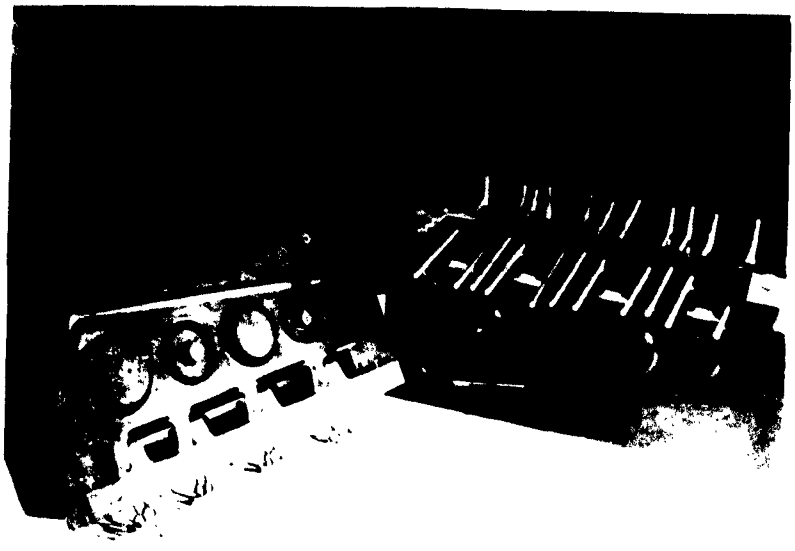
All metal to mold cavity is fed into thin sections with "ferrostatic" pressure, (determined by height of head), metal, and rate of flow controlled to minimize movement of metal in mold, thus controlling uniformity of solidification through rate of flow, metal travel and thermal balance. Angle of mold is adjusted to control rate and direction of metal flow.

Ingates are individually metered for flow control. Mold is angled so that head is filled last with hot metal after metal has filled mold through thin section. Rectangular head provides approximately 50-50 dimensional and internal volumetric shrinkage by collapse of flat sides. Mold cavity is vented through ceramic head vent core which also admits atmospheric pressure beneath skin of foetal casting.

Photo #2: Shows two halves of mounted pattern. Mold core print by which casting core and gate cores are located and held. Ceramic gating components are rammed in left core box. Right core box makes casting core.

SECTION II - CHASE C-123-B MAIN LANDING
B. EXPERIMENTAL PRODUCTION of CASTINGS in CONTRACTOR'S NORMAL TO PROVIDE PHYSICAL FORMS

1. PHOTOGRAPHS OF MOLD, PATTERN,



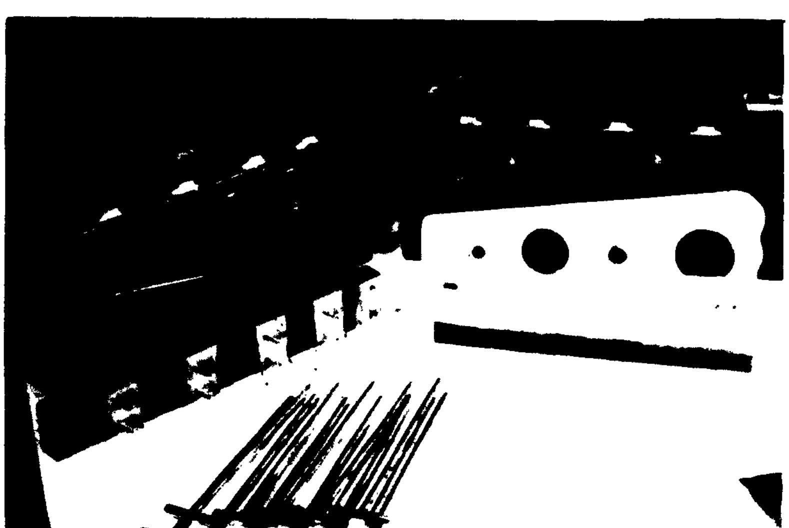
3

<u>Photo #3:</u> Shows core box open with removable, fully radiused ingates dimensionally adjustable by interchange.

<u>Photo #4:</u> Note accurately located brass vent rods providing vents to by-pass steam, and gas from combustible core bonds, generated by metal heat.

4

<u>Photo #5:</u> Shows core produced in box and removable ingate components mounted in core box section orifice control by interchange as desired. Wood patterns and core box are employed for economy in production of casting to produce casting in contractor's production Chrome-Nickel alloys for physical forms, not material evaluation. It is specifically noted that casting of physical integrity, of controlled "grain size", dimensional and surface finish, and of acceptable "aircraft quality", can not, in Contractor's opinion, be produced from wood patterns or in "green", "dry", or "shell" sand molds bonded with organics, particularly in such thin, (1/8", and under, sections). Contractor has recommended employment of <u>ceramic molds</u>, <u>centripetally cast</u>, under close <u>temperature, pressure and atmospheric controls</u>, to obtain "High Integrity" castings.



5

GEAR DRAG LINK ATTACHMENT FITTING
HEAT RESISTANT ALLOYS FROM WOODEN PATTERNS IN SAND MOLDS FOR STRESS EVALUATION ONLY.

CORE BOXES AND CERAMIC GATING.

Photo #6: Shows portion of ceramic gating assembled in core.

Photo #7: Ceramic cone from gang skimmer feeder shaped to feed dual ingates.

Photo #8: Non-eroding downgate terminal with vented cover.

6

Weight of finished steel casting was 16 pounds as against weight of finished steel forging of 20 pounds. (Note: It is noted that less machining of castings is required than on forgings due to the seven degree die-draft of the rough forging which is often machined off. Draft on the cast flanges and other machining areas was 2° and can be eliminated. Attainable accuracy in projected castings should eliminate a large part of the machining and permit finishing of remaining previously machined areas by grinding.)

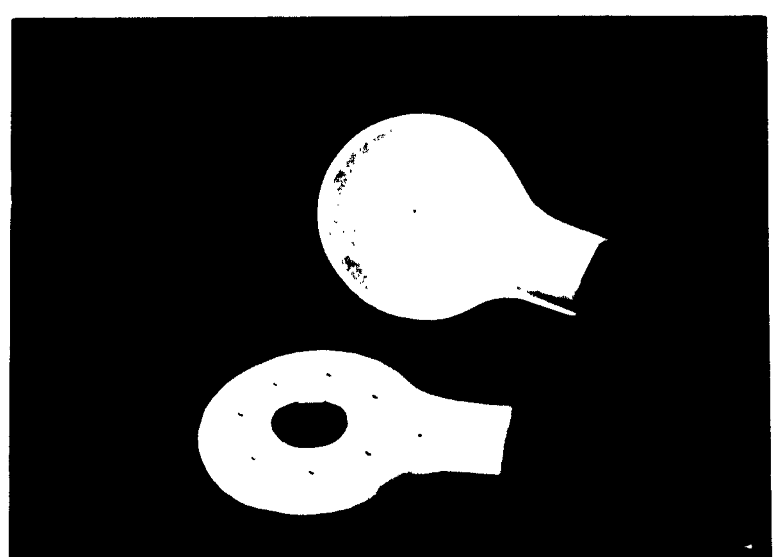
NOTE: Design of this casting varies in section from 1-1/4" at the end attaching boss to 1/8" in the wall section with section increased to 1/2" on opposite end and with 1/4" section in flanges to allow for machining. This is a grossly irregular section and undoubtedly has an excess of strength and weight in the major thick sections. This section could not be reduced in critical outside dimensions and provide interchangeability. It is planned to reduce section and weight at this point by extending the projected ceramic core to remove any surplus metal in the thick end.

CERAMIC GATING COMPONENTS AND RELATED TECHNIQUES DEVELOPED BY CONTRACTOR AND GENERAL ALLOYS COMPANY (patents pending) are employed to:

A. Accurately meter metal at desired rate.

B. Prevent erosion in gating system and introduction of "dirt" into mold.

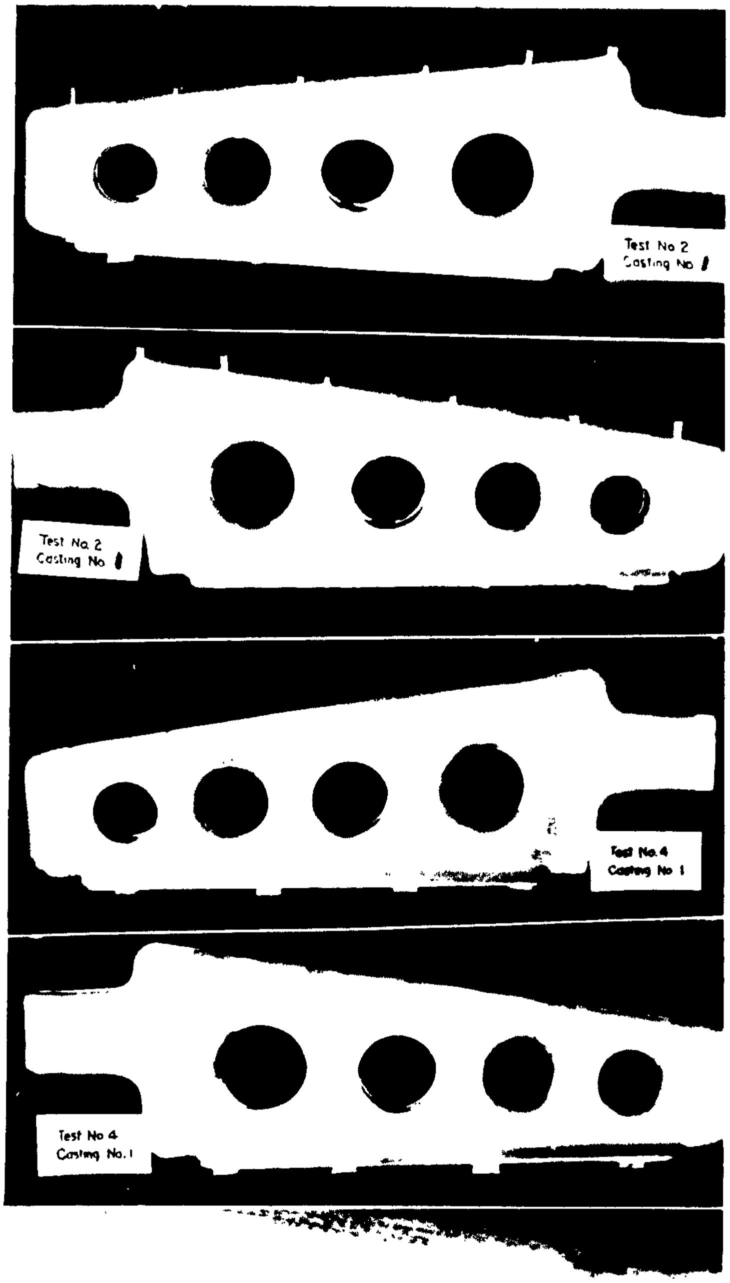
C. Prevent steam and gases from oxidizing metal in gating system and its introduction into molds.



SECTION II - CHASE C-123-B MAIN LANDING

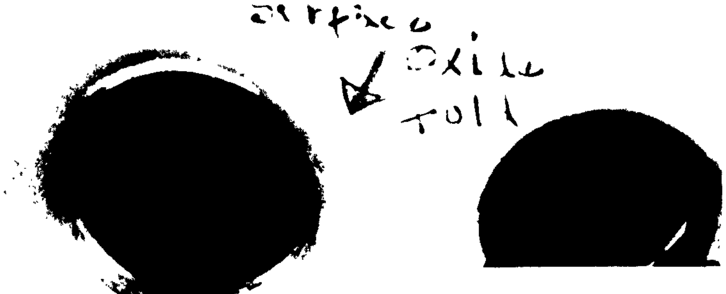
EXPERIMENTAL PRODUCTION of CASTINGS in CONTRACTOR'S NORMAL
TO PROVIDE PHYSICAL FORMS

2. PHOTOGRAPHS OF



Comparison of the nickel - chrome alloy castings, pictured here, with the high alloy steel casting in Item D-2 following, indicates little difference in the castability of the different alloys. In casting centripetally in ceramic molds, the "fluidity" of the alloy, as considered by conventional sand casting standards, is of negligible importance.

Castings were deliberately poured both "cold" and "hot". Example of cold pouring is Casting #2, Test #5. (Metal solidified before fully filling a mold.) Examples of hot pouring are Casting #1, Test #5, showing excessive shrink under vents extending to areas of centerline shrink, and Casting #1, Test #4, indicating surface oxide fold.



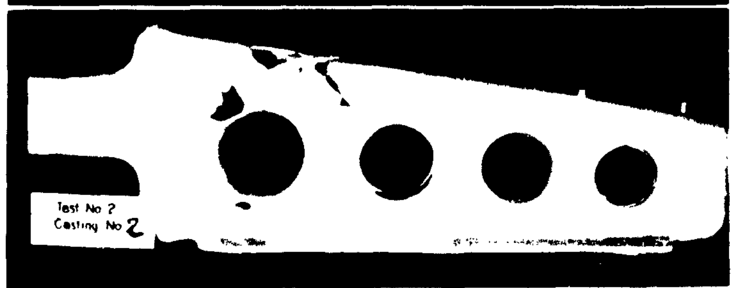
Test No. 4
Casting No. 1

GEAR DRAG LINK ATTACHMENT FITTING

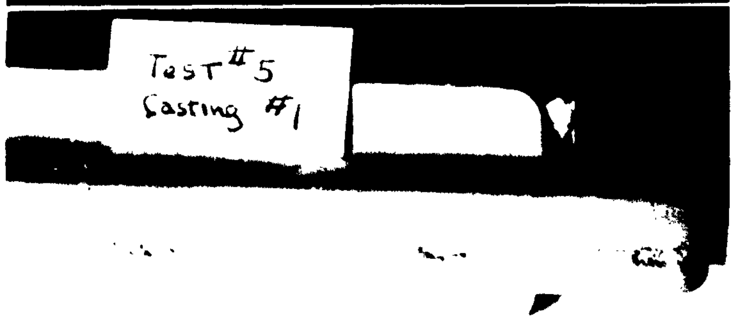
HEAT RESISTANT ALLOYS FROM WOODEN PATTERNS IN SAND MOLDS, FOR STRESS EVALUATION ONLY.

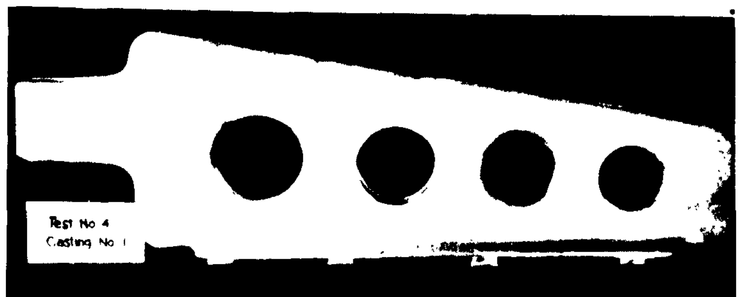
EXPERIMENTAL CASTINGS.

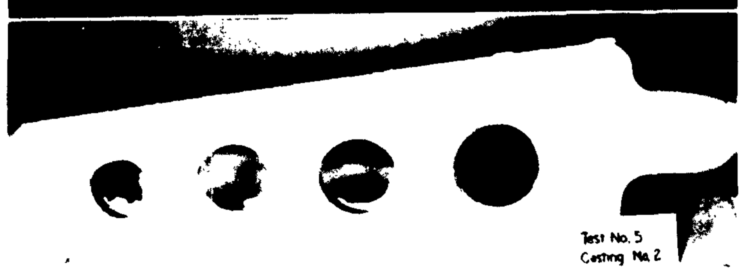
Vents (indicated by small projections at top of casting) were eliminated by modification of "head" and placing "head" in position to provide venting by straight line steam egress from casting to head and through head vent core.

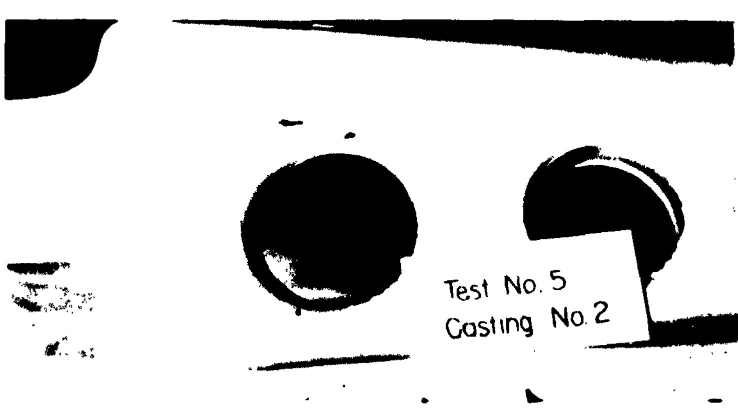


All castings are shown as-cast and sand blased, with heads and gates removed (exception Casting #1, Test #4, which was spot ground to indicate extent of surface defect shown.) Casting, complete with heads and gates, original gating, is shown, Photo #G-1, as removed from mold with some sand and fragments of ceramic gating remaining. (Same gating, with modified head, final H. R. alloy and steel castings, is illustrated in Section II, Item D-2.









SECTION II - CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING.

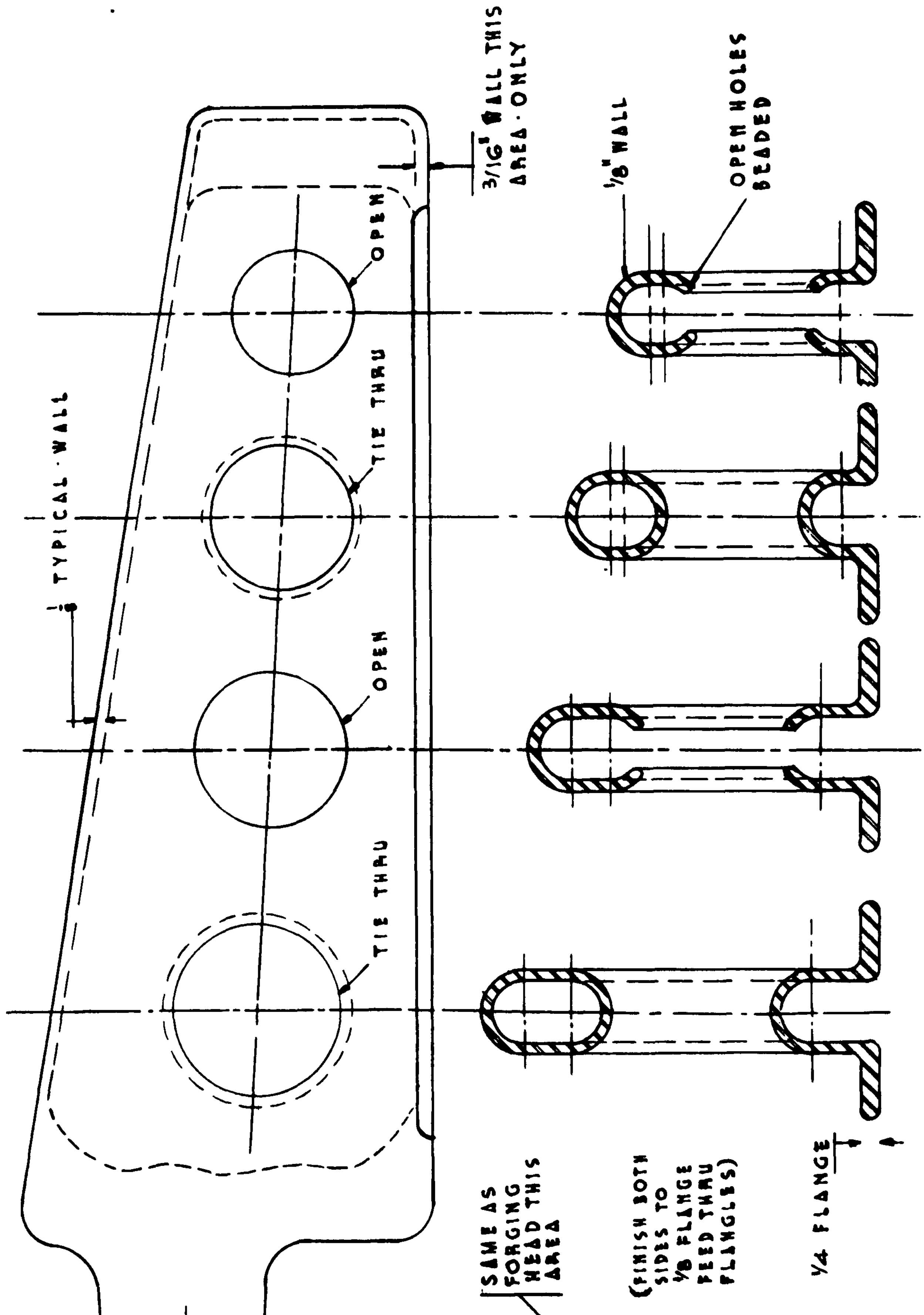
B - 3. TYPICAL ANALYSES and PHYSICAL PROPERTIES of NICKEL-CHROME H. R. ALLOY STRESS-TEST MODEL CASTINGS (in Contractor's Commercial production cast to provide physical forms for stress evaluation of design only.)

MATERIAL		ANALYSIS		
Induction Furnace Charge		Figured		Actual
Ni	39	35%	Ni	37.2
FeCr (.05C)	19	15%	Cr	15.5
FeCr (6%C)	4	.50	C	.48
Steel	38	1.50	Si	1.62
FeSi	5			
FeMn	2			
CaSi	1/4			

TYPICAL AS-CAST PHYSICAL PROPERTIES of SAMPLES CUT from CASTINGS of CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING.

Material: 35% Nickel - 15% Chromium -- Standard A. S. T. M. Flat Bars

BAR	LOCATION	YIELD	TENSILE	Elongation in 2"
XB-1	1/4" section flange	55,100	83,300	6.0
XB-2	1/8" section Body	53,000	80,400	5.0



CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

"CASTING POTENTIALS PROJECT"

SECTION II - CHASE 123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

C. - Illustrated Report of Stress Testing and Evaluation of Nickel-Chrome Alloy Stress Test Model Castings for Design Evaluation Only.

Note: Photos, Numbered 1 to 10 inclusive, and Charts, Numbered 1 to 15 inclusive, are attached in numerical sequence, as referred to in text.

1. Laboratory Procedure:

In order to conduct an experimental stress analysis of the cast landing gear fitting, Design CP-518, it was necessary to design and construct a static test fixture, Fig. 3, (A. E. C. Co. Dwg. CP-572). This fixture was capable of subjecting the casting (Fig. 1 and 2) to design load conditions, established by the Chase Stress Analysis Report. Prior to stress-coating, the steel casting was vapor degreased and assembled into the test fixture. The casting and mating parts were thoroughly brushed with clean acetone and given a final wash with spray gun and ethyl acetate. The entire assembly was pre-heated to approximately 100 deg. F. The casting was undercoated, sprayed with stress-coat, and dried at 100 deg. F. for four hours. The temperature of the entire assembly was slowly reduced to approximately 75 deg. F. in order to obtain the desired threshold sensitivity in the stress-coating.

Next, the casting was loaded in increments until the final load of 65,000 lbs. was reached. Areas of high stress concentration were noted and circled at each successive loading, Fig. 4.

SR-4 Strain gages were properly oriented in these areas in order to obtain maximum stresses. Due to the complex state of stress that existed in certain areas, Fig. 4, T-gages were installed as required. In such cases, the measured strains were related to stress by the equation, $S = \frac{E(e_1 + \mu e_2)}{(1-\mu^2)}$, and for the simple state of stress, $S = Ee_1$.

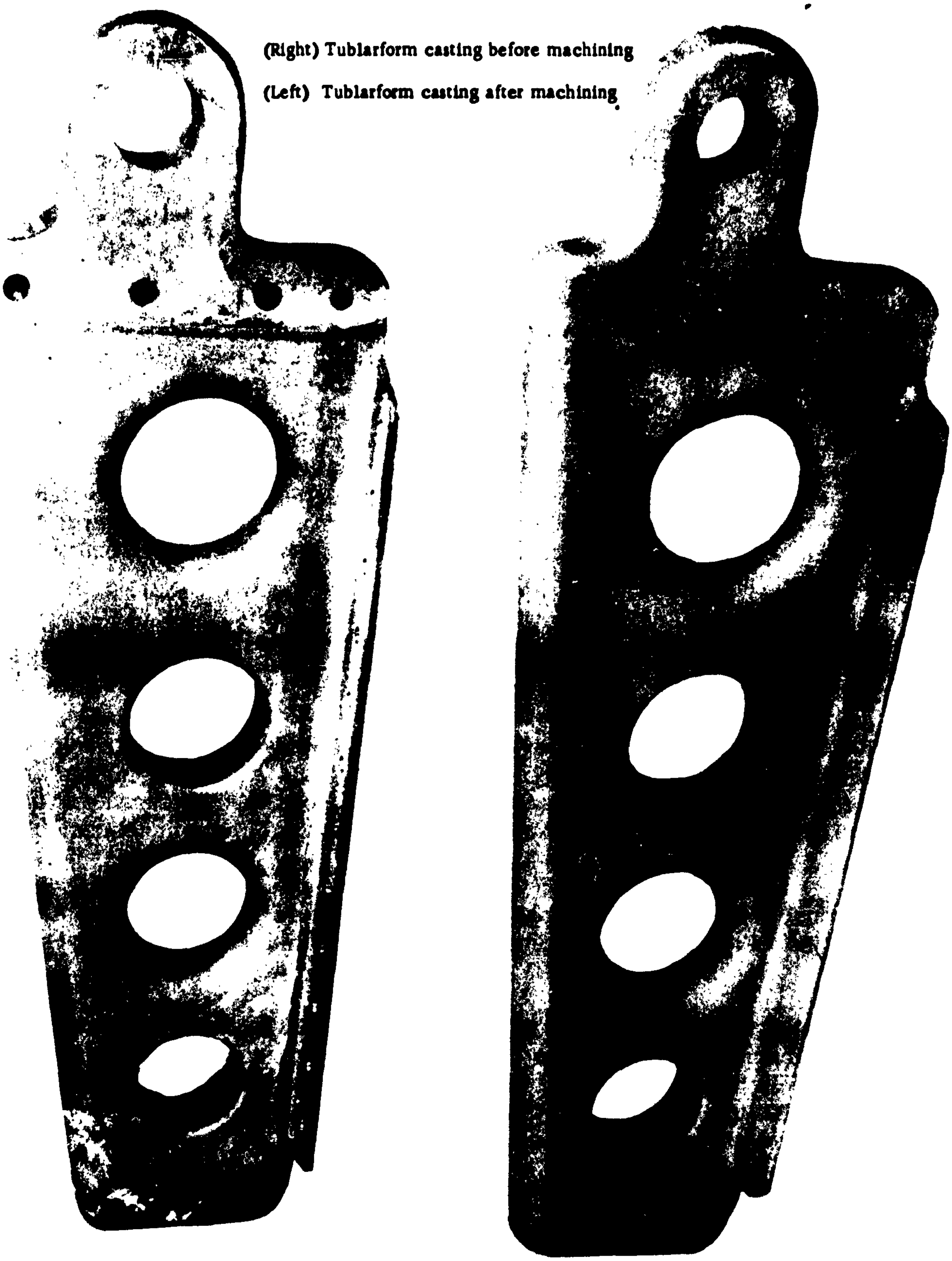
The most highly stressed areas in the casting were located at Point "A", Fig. 4, and Point "B", Fig. 5. The strain gage data correlated with the stress-coat indications.

The casting was subjected to a final load of 65,000 lbs. and all notations of stress, Figs. 6, 7, 8 and 9, were based on this load. Strain gage data was recorded for three load increments below 65,000 lbs. in order to aid in extrapolation of data to design load of 121,700 lbs. Stresses at Points "A" and "B", Figs. 4 and 5, established a straight line relationship with load.

2. Static Strength:

Now that stress distribution of the steel casting has been established, the test results must be compared with material strength and interpreted in terms of serviceability. At a design load of 121,700 lbs., the elastic tensile stress at Points "A" and "B", Figs. 4 and 5, would be 231,000 and 245,000 psi respectively.

CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
Redesigned as a tublarform steel casting to replace an I-beam section steel forging



Weight 16.0 lbs. Weight 17.25 lbs. NOTE: Weight of forging 20.5 lbs.

"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 2

TUBLARFORM CASTING FOR CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING, IN HYDRAULIC TEST RIG. DESIGNED AND BUILT ON PROJECT.

The ordinary tensile strength of a material is not an absolute index of local material strength and, therefore, may be exceeded by a rather large margin under certain local plastic flow conditions. It is a well known fact that beams in bending sustain a much higher ultimate lead than would be predicted from classical beam formulae (providing local buckling does not occur). This is due to the fact that local yielding of the outermost fibers alter the normal elastic stress distribution. Under these conditions, allowable stresses in bending are based on the modulus of rupture of the material and not on elastic stress formulae, nor on the plastic flow characteristics established by a test bar in simple tension. Equally well known, is the fact that in a material, when subjected to a tri-axial state of stress (such as that existing in a severe notch), the local elongation of the material may be increased several hundred per cent.

Test data on the steel casting indicated that Point "A" was subjected, primarily, to bi-axial tension, whereas Point "B" was subjected, primarily, to bending. (The nominal tensile stress at Point "B" was 32,800 psi and cannot be overlooked.) Therefore, the static strength of the casting at Point "A" will be limited by the plastic flow characteristics of the material in tension, whereas the static strength at Point "B" will be limited by its modulus of rupture.

Curve No. 1 compares the tensile strength of cast steel with its yield strength and elongation. The yield strength and elongation at a tensile strength of 180,000 psi would be 150,000 psi and 12% respectively for a normalized chrom-moly steel quenched and tempered. The mechanical behavior of the material when loaded in simple tension will be considered.

By making simultaneous observations of load and elongation, a load-extension curve can be drawn. This load-extension curve is commonly, but erroneously, referred to as a stress-strain curve. No great error exists while the specimen is undergoing elastic deformation and before the dimensions of the bar have changed appreciably, due to plastic deformation. If, however, the length of the bar continues to increase until plastic deformation takes place, the cross sectional area supporting the load is correspondingly reduced and the true stress will be considerably higher than that computed on the basis of the original area. Simultaneously, the increase in strain must be based on the change in length divided by the prior increment length or $\Delta\epsilon = \frac{\Delta l}{l}$. The total strain at any point is $\int_{l_0}^{l} \frac{dl}{l}$. This is the true strain and should be used in correlating strain gage data with test bar data.

At an elongation of 12%, the true tensile strength of 180,000 psi steel would be 200,000 psi at a true strain of 0.112 in./in., Curve No. 2. By using "Post-yield" wire strain gages, an accurate study can be made of the plastic behavior of metals prior to necking. Such studies reveal that the plastic flow characteristics of most metals form a straight line and tend to converge at a common point when plotted on logarithmic paper, Curve No. 3.

Thus, the plastic portion of the stress-strain curve can be described by a simple equation $S' = K\epsilon^N$, where S' is true stress, ϵ is true strain, K is the strength coefficient of the material and N is the strain hardening exponent. The line AB, Curve No. 3, is established by connecting S'(200,000 psi and 0.112 unit strain) to Point "O". The true stress at Point "A" is 164,000 psi. K is 238,000 psi and is established by Point "B". An enlarged section of line AB is shown in Curve No. 4.

A linear plot of the plastic flow curve may be connected to the elastic portion via the yield strength point, Curve No. 5. Therefore, the mechanical behavior of the steel, as subjected to simple tension, may be compared with the static stress data. Insufficient static strength is indicated at Point "A".

A simple way to relate strain measurements taken in the elastic range to strain conditions beyond the elastic range, is to specify elasticity with regard to the maximum recoverable deformation. From Curve No. 5, the maximum recoverable deformation in terms of the unloading process is 0.0066 in./in. While it is evident, from a study of stress-strain diagrams, that the total strain depends not only on stress, but on previous strain history, strain rate, state of stress, temperature, etc., there is one common feature in the behavior of metals when strained beyond their elastic range, i.e. the instantaneously recoverable elastic strain.

It is evident that the 180,000 T.S. material cannot recover sufficient elastic deformation to accommodate the elastic strains imposed on the casting at Point "A", Fig. No. 4, if the casting is subjected to its design load. Static failure would result.

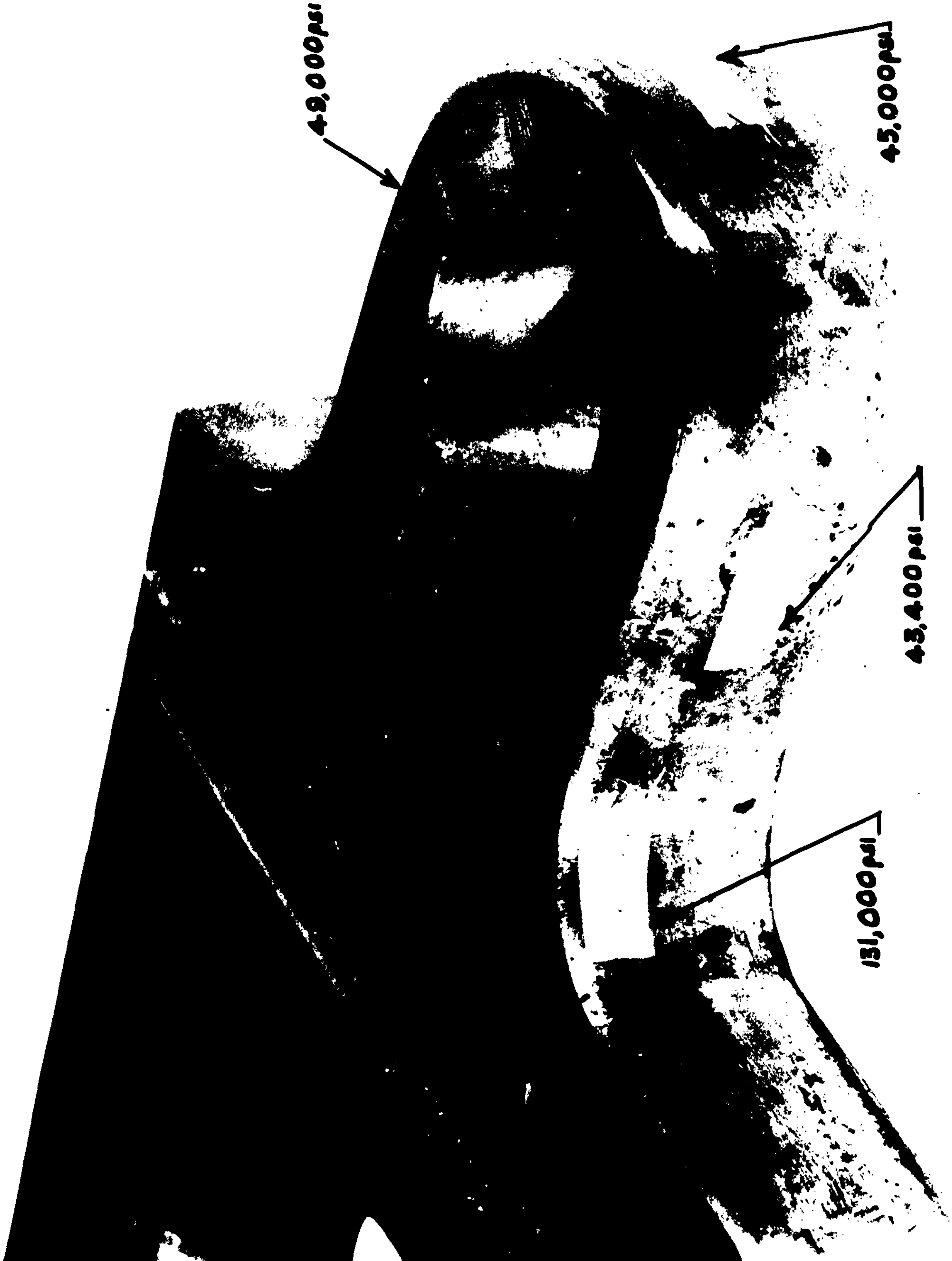
Point "B", Fig. No. 5, differs from Point "A" in that the outermost fibers in fillet can be expected to develop greater ultimate strength than would be predicted from simple tension specimen, due to the reinforcing action of the sub-surface material that is nearer to the neutral axis in bending and, consequently, not yet overstrained. Since local buckling cannot occur at Point "B" (due to the geometry of the section), a modulus of rupture factor of 1.5 can be realized. The margin of safety (neglecting the tensile stress due to the axial load) is M.S. $= 180 \times 1.5/245 - 1 = 0.10$. However, when the action of the nominal tensile stress present at this section is considered, the safety margin is reduced to 0.04. Since the bending moment at this critical section would be increased by a factor of two for the "Extended" load condition, an insufficient margin is indicated and static failure would result. (Point "A" is less critical under the "Extended" load condition.)

3. <u>Recommended Design Changes:</u>

In order to lower the stresses at Points "A" and "B", the design changes shown in Fig. 10 should be incorporated. Stress calculations indicate that the stress reduction at both points would be between 30 and 40 per cent, while the weight of the casting would be increased only 8 per cent. The final weight reduction of the casting

STRESS TESTING CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
STRAIN GAGE INSTALLATION SHOWING STRESS DISTRIBUTION
LOCATION AND ORIENTATION ESTABLISHED BY STRESSCOAT



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 5

compared with the forging would be 16 per cent.

4. Endurance Strength:

When the recommended design changes are made, the maximum stresses at Points "A" and "B" may be estimated as follows: Point "A", 231,000 x .66=153,000 psi, Point "B", 245,000 x .66 162,000 psi. Since the design changes will provide adequate static strength, serviceability in terms of endurance life should be considered.

The relationship between the tensile strength and the endurance strength is shown in Curve No. 6. It should be noted that the allowable cyclic stress in the notched specimen reaches a peak at 180,000 psi. Allowable cyclic stresses also vary with the number of load cycles. An S/N curve for 180,000 T.S. steel is shown, Curve No. 7. The brittle failure zone indicated on this curve will occur only at low temperature and under impact loads. Ductile failures can be expected in this zone under normal conditions. S/N curves for high and low carbon steels are compared in Curve No. 8. The S/N curves shown are based on the plain (or un-notched) and the severely notched specimens. Nominal stresses are used in both cases. Structural components, unlike test specimens, frequently fall somewhere between these two curves.

Curve No. 9 shows how the notch factors vary with fillet radius. It should be noted that the actual strength reduction factor K_F is less than the theoretical factor K_T. The term "q" is an index of the notch sensitivity of the material. These curves can be utilized to simplify the interpretation of strain data in the following manner: a horizontal line is drawn tangent to the peak of the K_F curve until it intersects K_T; a perpendicular line from this point locates the critical fillet radius for the material. That radius for this particular material is 0.05 in.

A simple rule to follow in utilizing this information is: (1) on all notches, fillets, or holes having a radius greater than 0.05 in., apply the full notch effect, or 100% of the measured strain at the notch; (2) on all notches, fillets or holes of less than 0.05 in. radius, base the analysis on measured nominal strain and apply the highest K_F that the material will recognize. (In this case, maximum K_F is 2.5.)

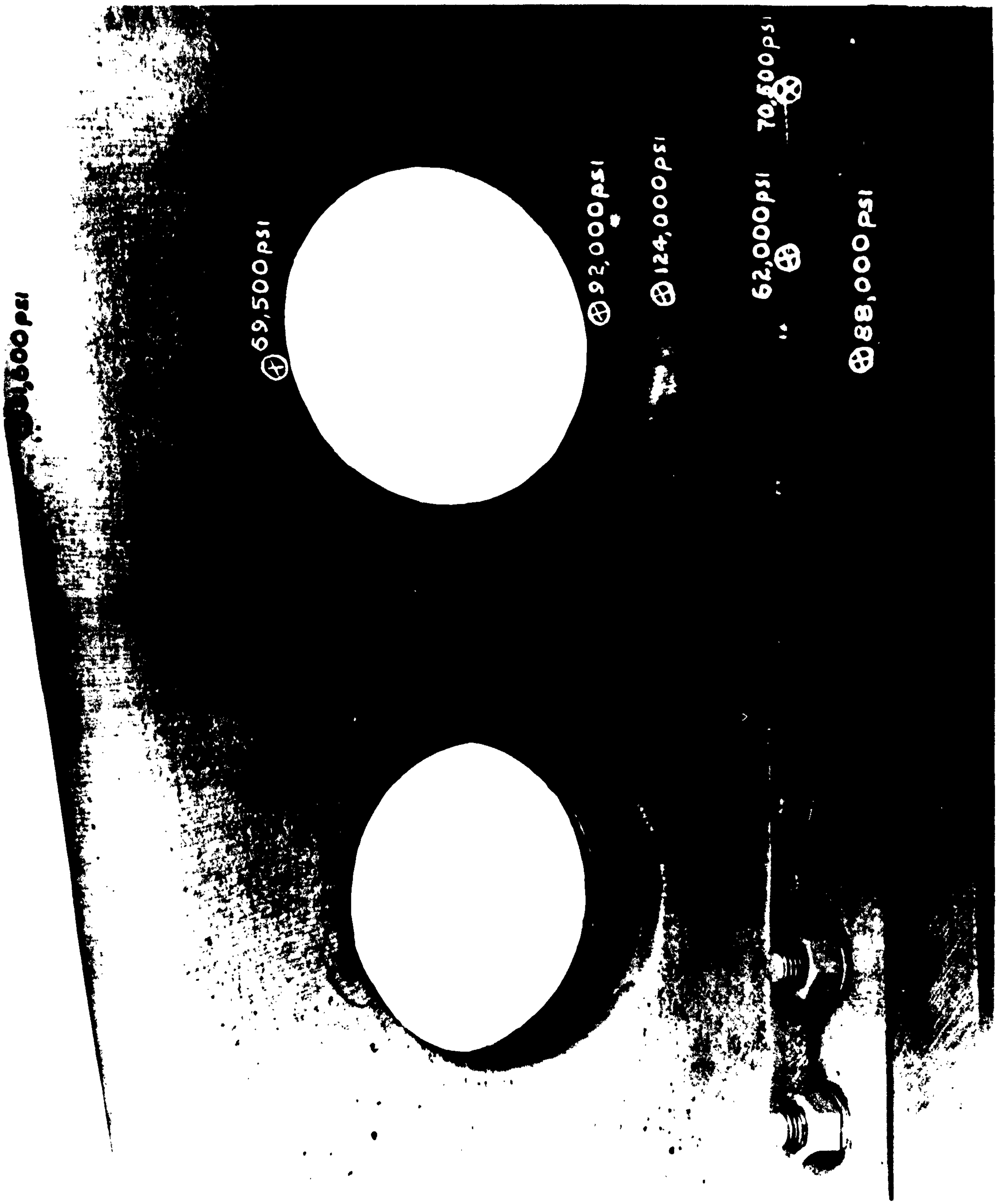
Allowable cyclic stresses also vary with the mean or average stress, Curve No. 10. This failure diagram is for direct stress and is constructed by drawing a 45 degree line through zero mean stress. The line terminates at Points "T" and "C", the true tensile and compressive strengths of the material. The allowable static stresses shown are, of course, the ultimate strengths in tension and compression. The maximum allowable stress range from the static diagram is $\neq$240,000 psi and requires an initial compressive stress of 40,000 psi. (The initial stresses are located at the intersection of the cyclic stress line with the mean stress line.)

The static diagram indicates that the maximum allowable compressive stress at an initial compressive stress of 140,000 psi is 140,000 psi. Data for $N=10^2$ cycles is taken from the S/N curve of the material, Curve No. 7. Since the diagram is a failure diagram, instead of a fracture diagram, minimum endurance values are used. It is of interest to note that at $N=10^2$ cycles the values for the notched specimen are slightly higher than those for the plain specimen. This is due to the fact that the notched specimen locally strain hardens, due to plastic deformation at the notch. However, this increase in tensile strength at the notch results in an increase in resistance to plastic deformation. This condition limits the ability of the notched fatigue specimen to strain harden, decreases the fracture stress and produces a rapid decrease in fatigue strength with an increase in number cycles. At $N=10^3$ cycles, Curve No. 11, the allowable cyclic stress for the notched speciman is lower than that for the plain specimen. Similar diagrams are constructed for 10^4 cycles, 10^5 cycles and 10^6 cycles, Curves No. 12, 13 and 14 respectively.

Curve No. 10 indicates that the maximum allowable cyclic stress for the plain specimen (all tension) is 160,000 psi. Curve No. 11 indicates the maximum allowable stress for the plain specimen is 140,000 psi (all tension). Therefore, the endurance life of the redesigned casting would be limited by the stresses at Points "A" and "B" (153,000 and 162,000 psi) to about 1,000 cycles. Incipient fatigue failures should be present in all castings at 10,000 design load cycles. The material has sufficient margin in the plastic region to prevent ductile failures prior to 1,000 cycles.

The effect of residual stress on allowable stresses may be interpreted by use of the failure diagrams. A residual compressive stress of 160,000 psi increases the allowable stress range at zero mean stress, as indicated by broken lines, Curve No. 14. Residual compressive stresses may be induced by processing or by prior static loading. Curve No. 15 shows the amount of residual stress induced in a fillet when plastic flow occurs, due to a statically applied load.

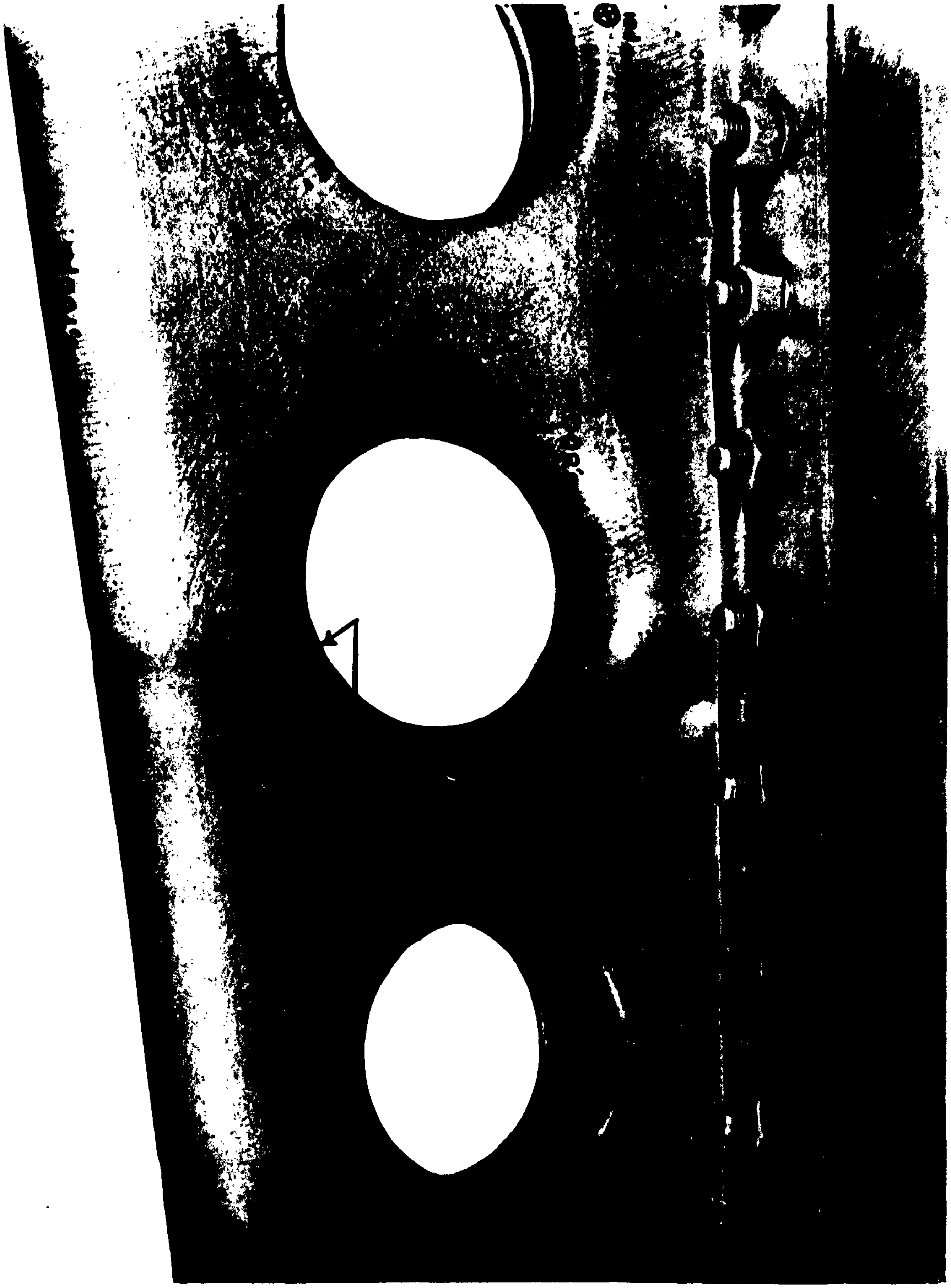
CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
STRESS DISTRIBUTION. STEEL CASTING CP-518



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 6

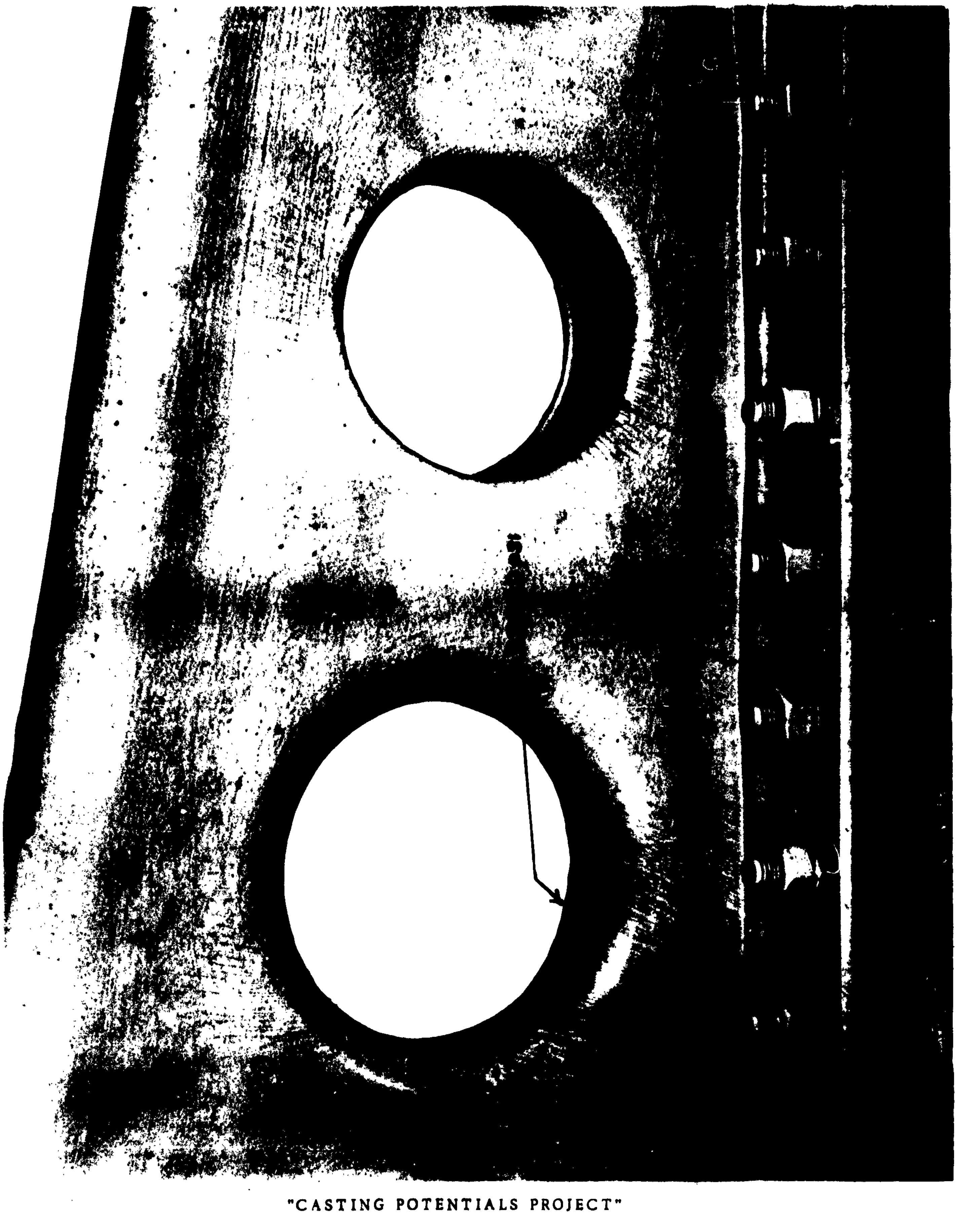
CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
STRESS DISTRIBUTION, STEEL CASTING CP-518



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 7

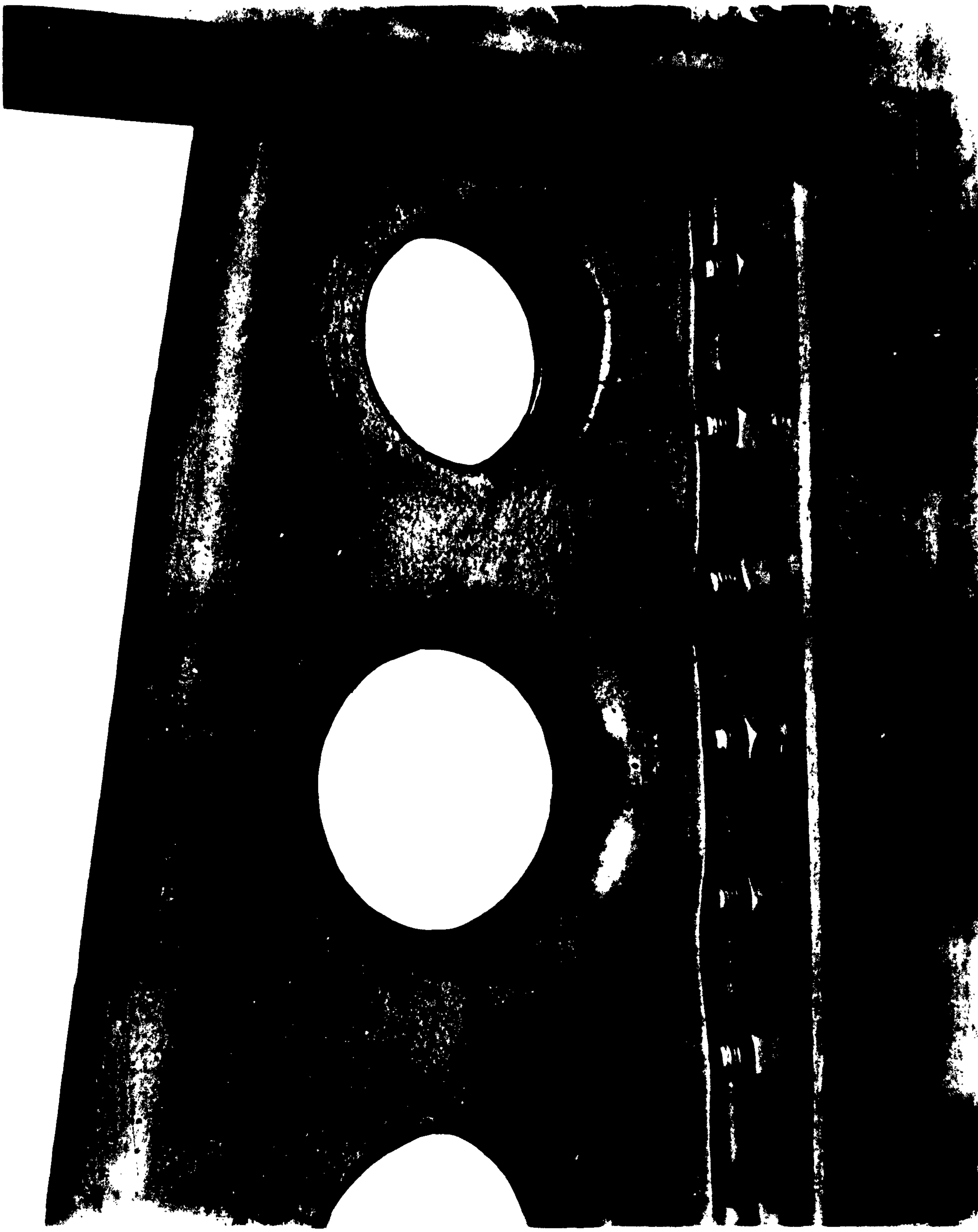
CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
STRESS DISTRIBUTION. STEEL CASTING CP-518



"CASTING POTENTIALS PROJECT"

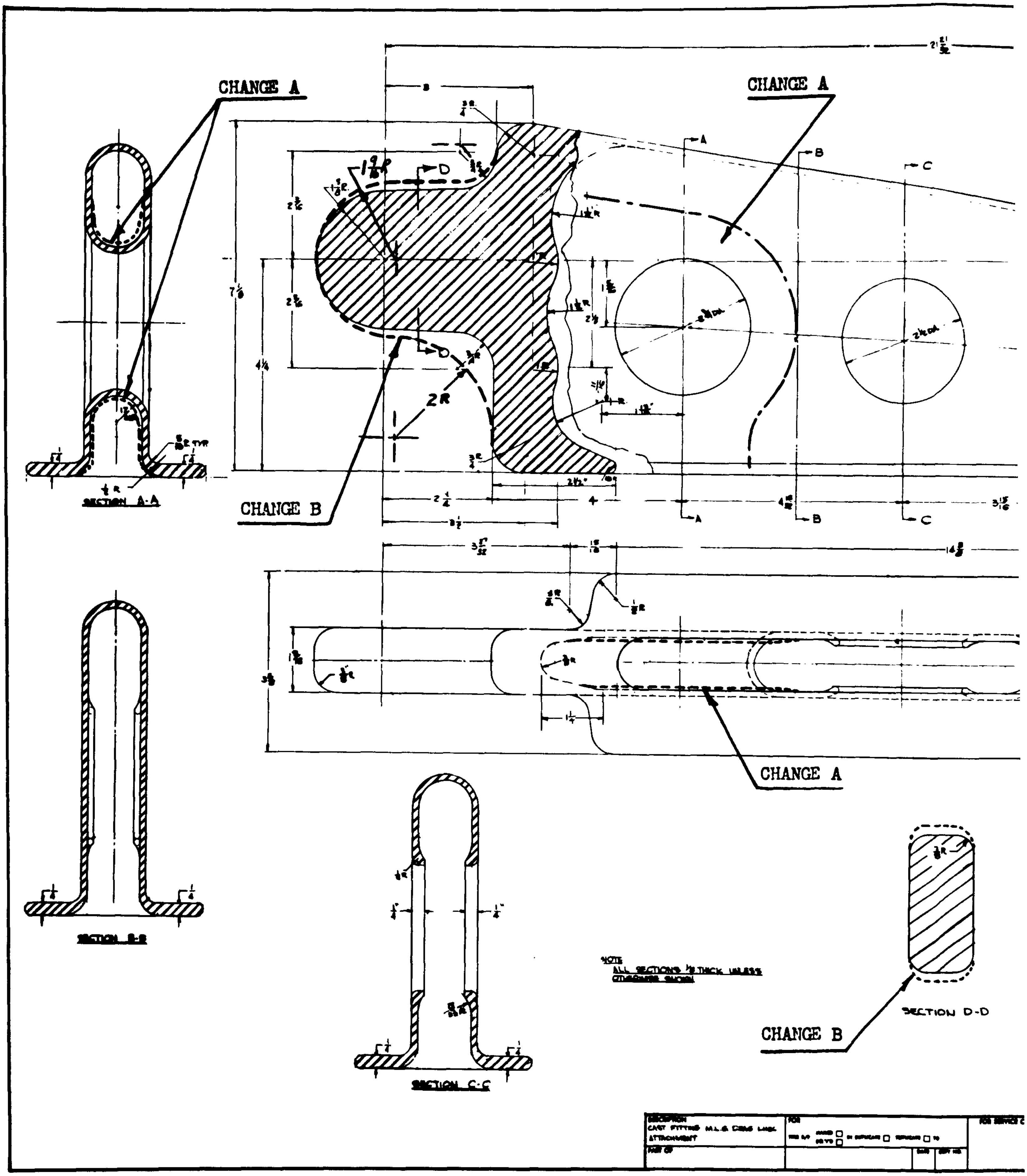
ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 8

CHASE MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
STRESS DISTRIBUTION, STEEL CASTING CP-518



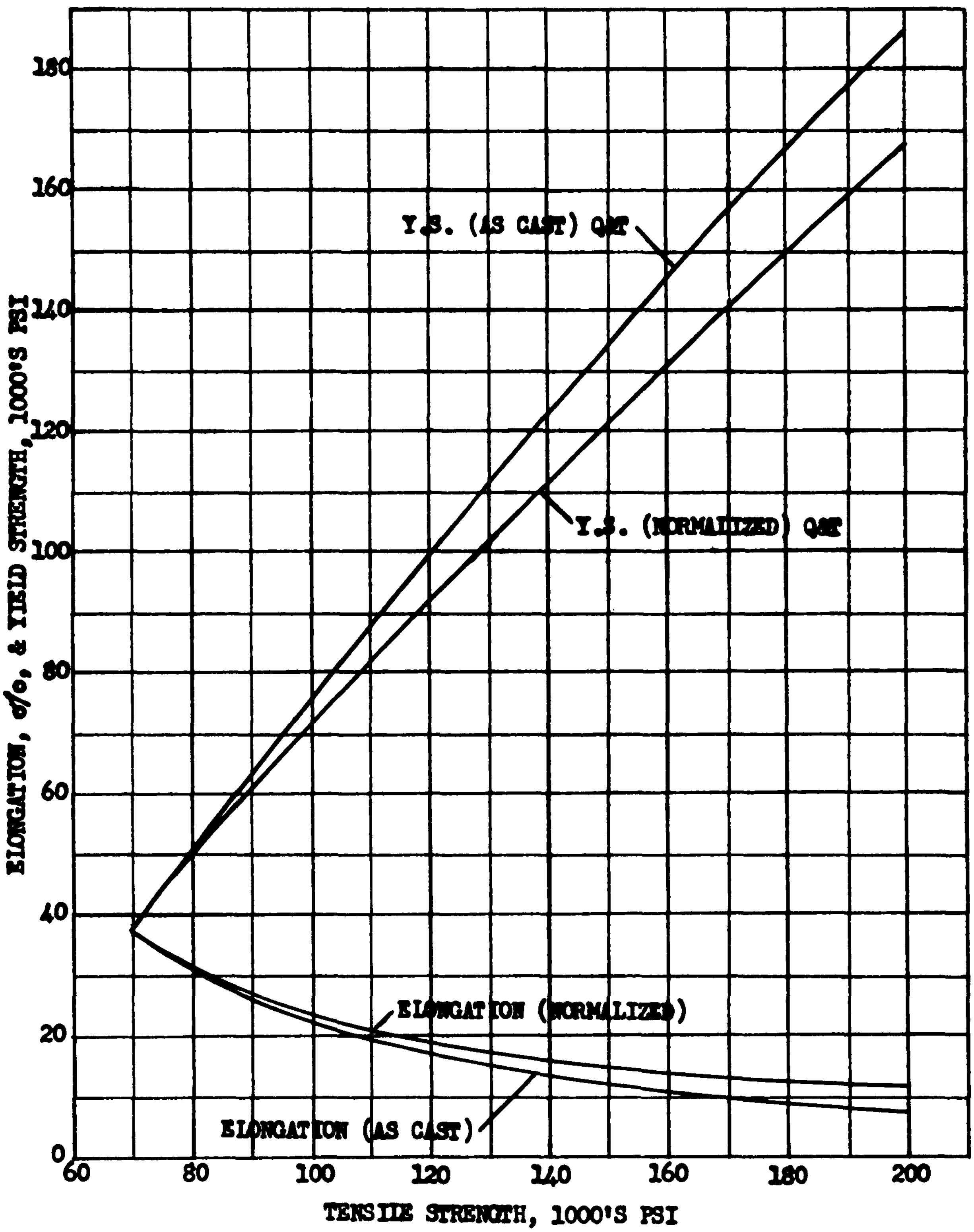
"CASTING POTENTIALS PROJECT"

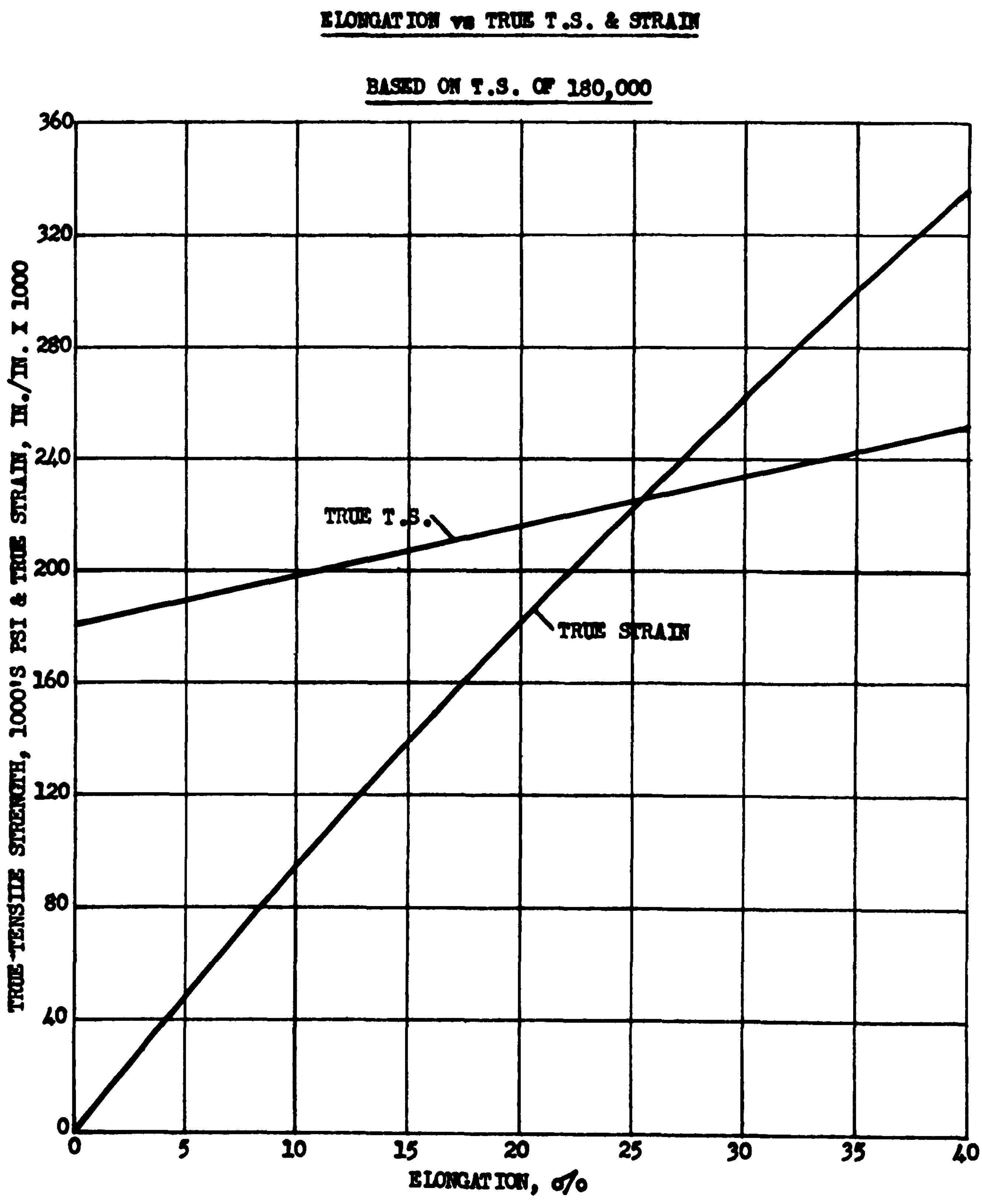
ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 9



CHASE C-123B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING
REDESIGNED AS "TUBLARFORM" HIGH-STRENGTH STEEL CASTING. A.E.C.CO. Dwg. NO.
REDESIGNED FROM CHASE PART NO. 8B-310307-1, Dwg. NO.8B310307, STEEL FORGI

T.S. OF CAST STEEL VS Y.S. & ELONGATION



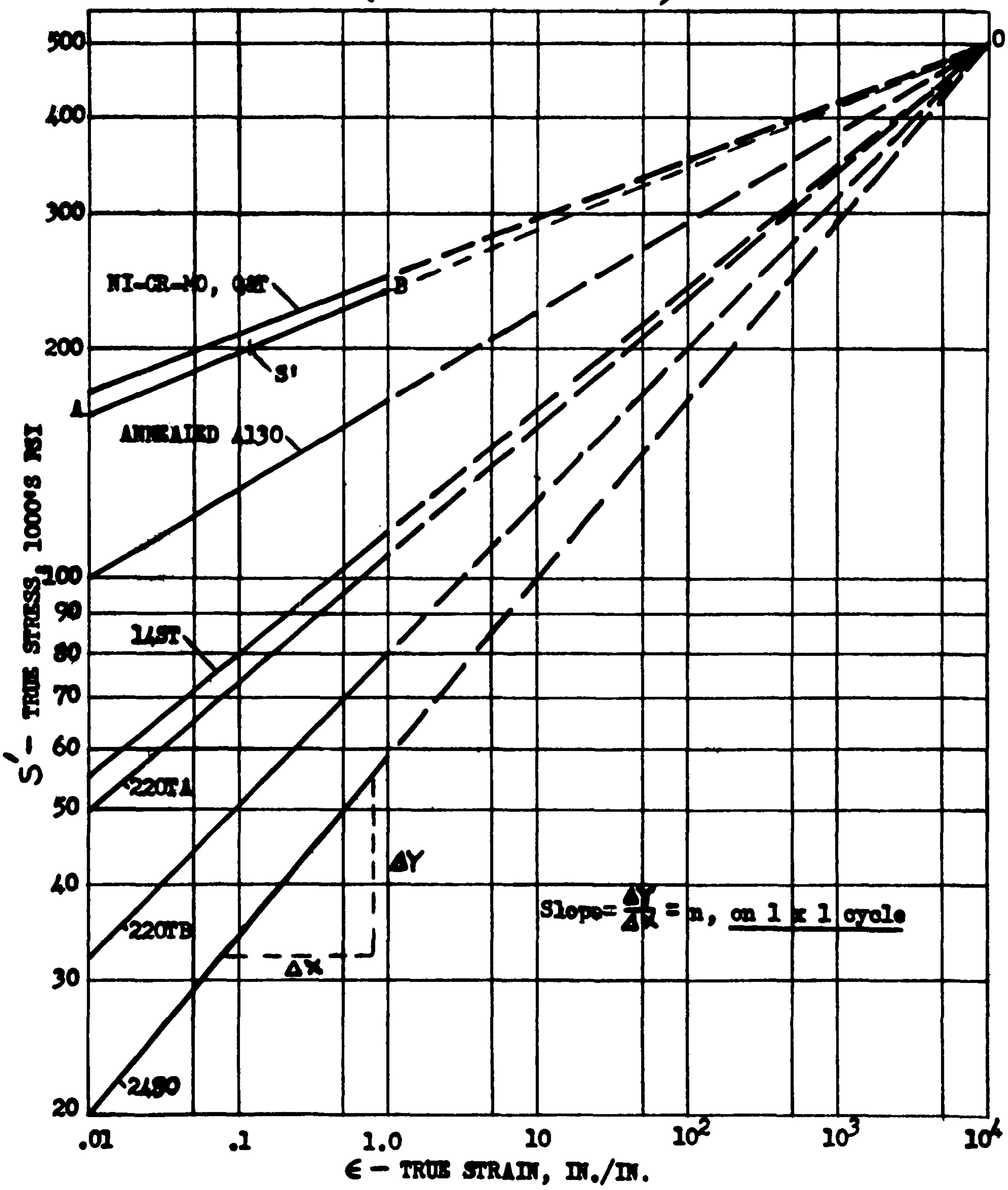


"CASTING POTENTIALS PROJECT"

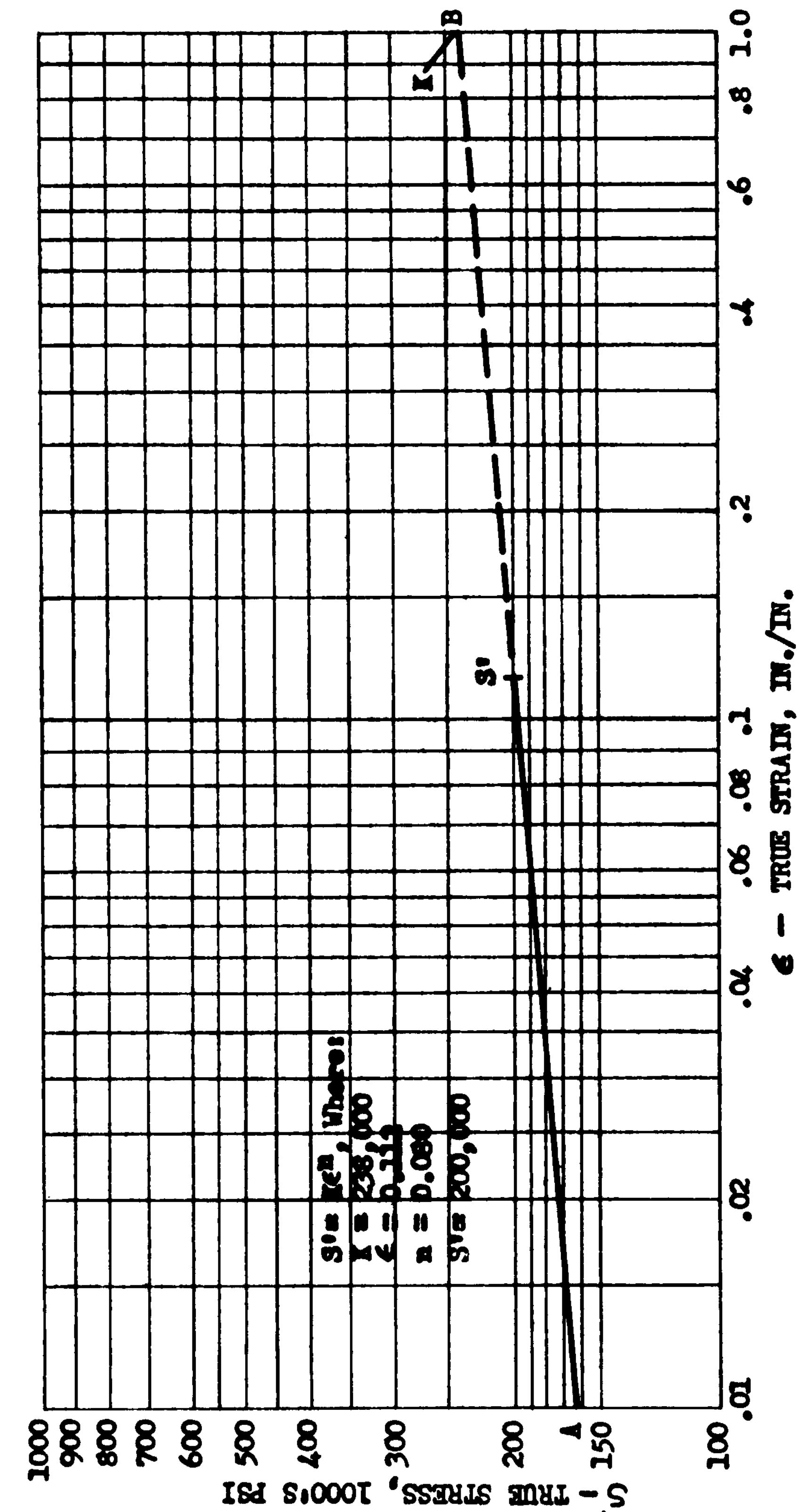
ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF

LOGARITHMIC STRESS-STRAIN CURVES FOR METALS

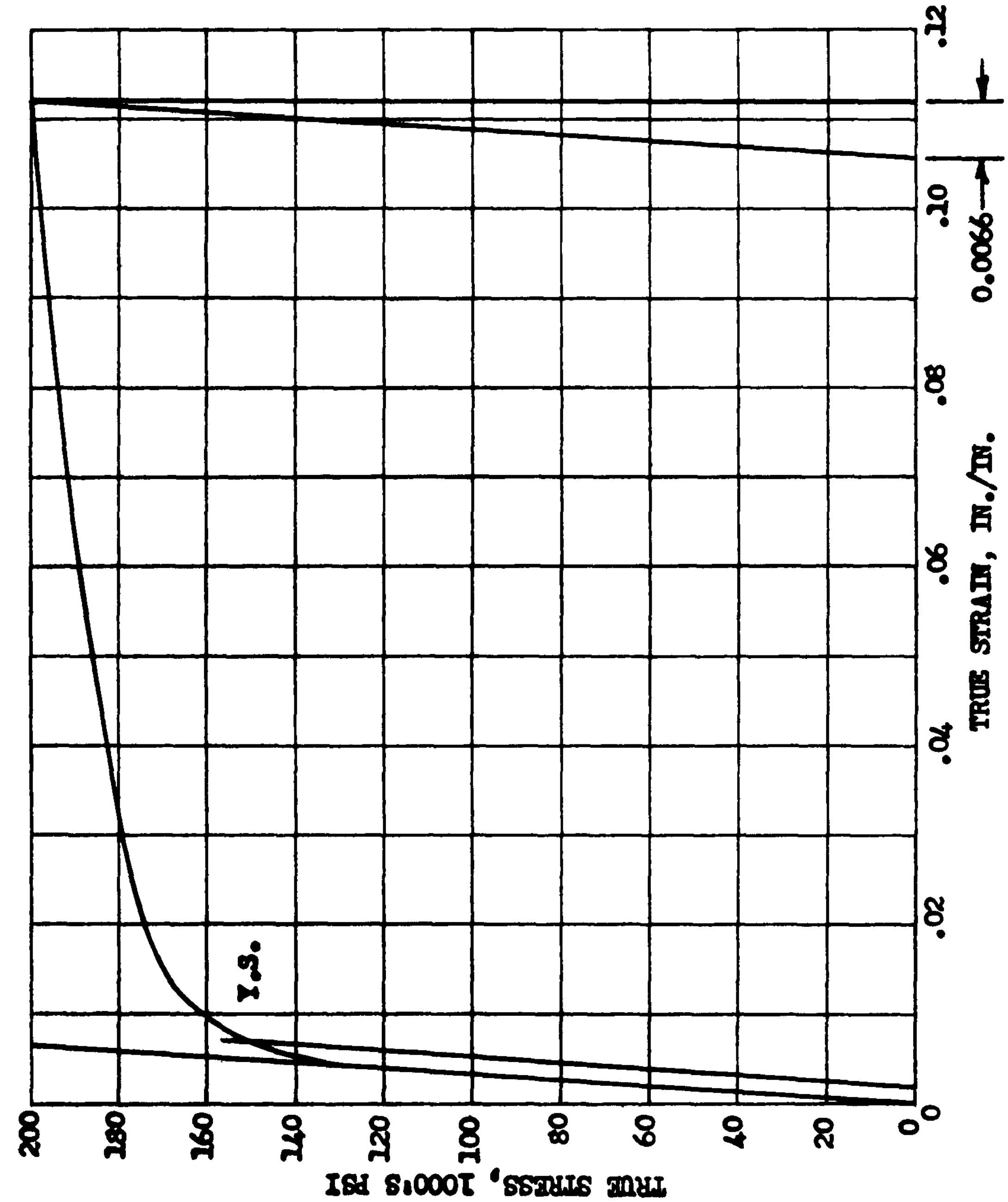
($S' = K\epsilon^n$ for All Curves)

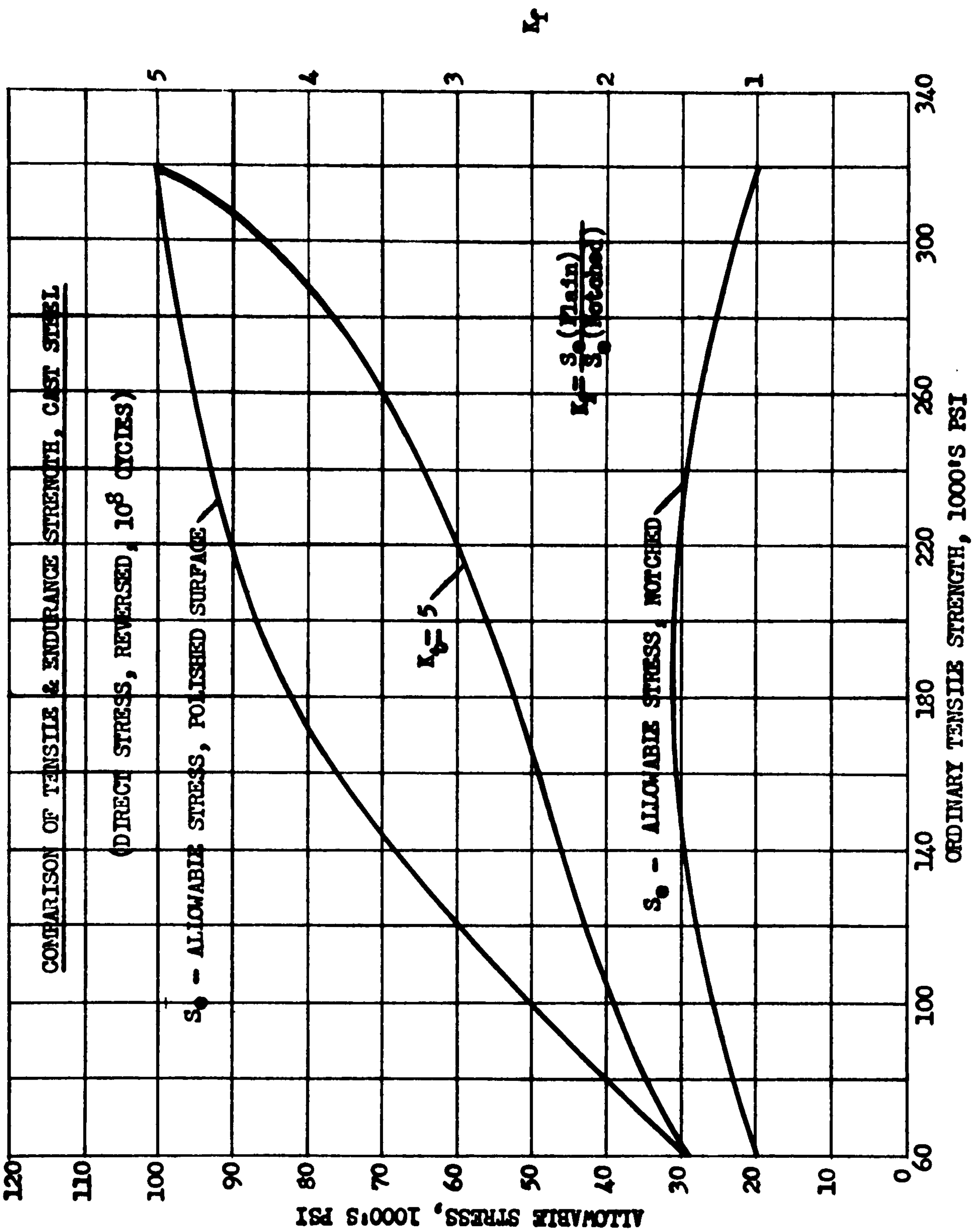


LOGARITHMIC PLASTIC FLOW CURVE FOR CAST STEEL, 400 BHN



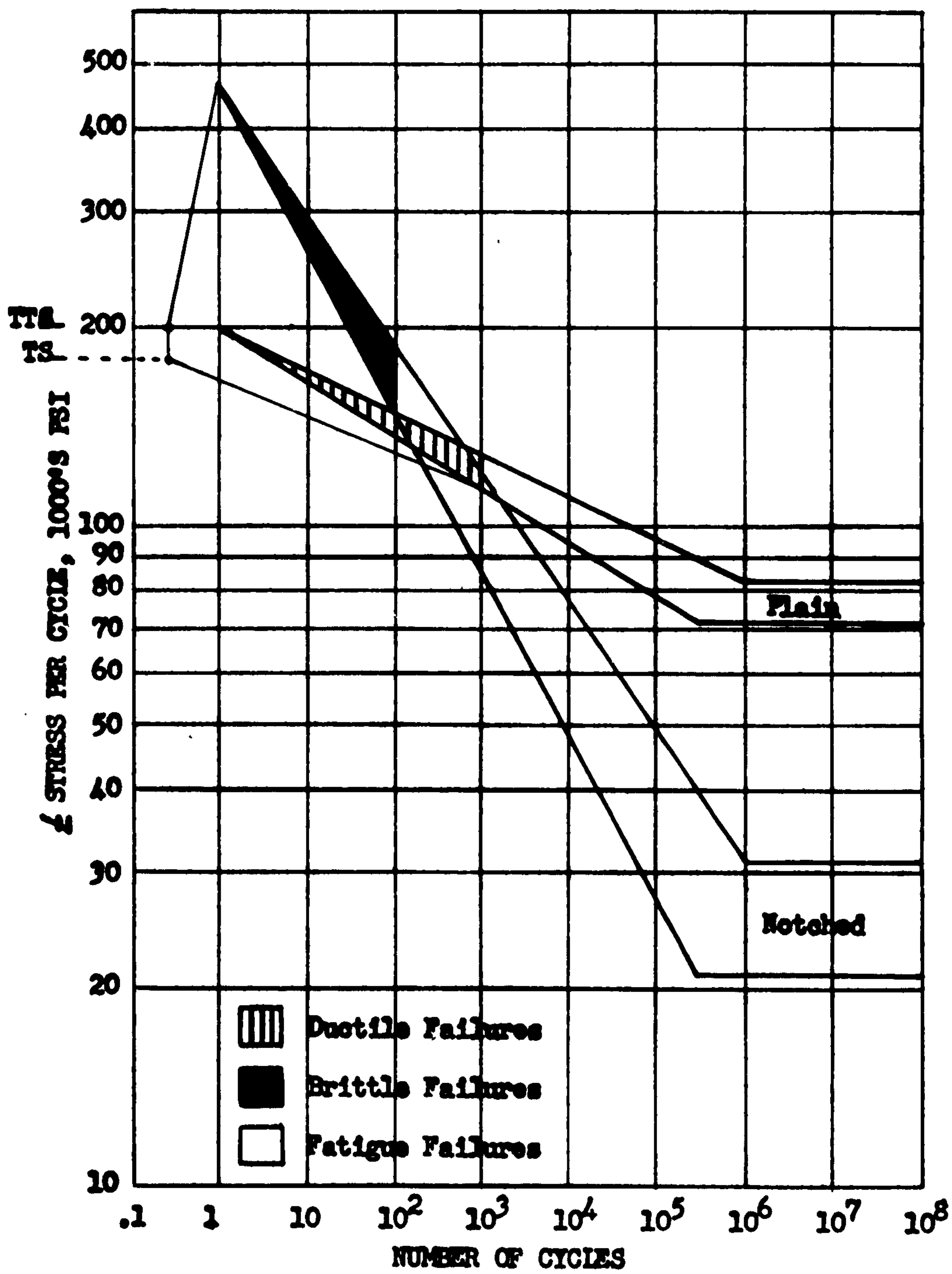
TRUE STRESS-STRAIN CURVE FOR CAST STEEL, 400 BHN

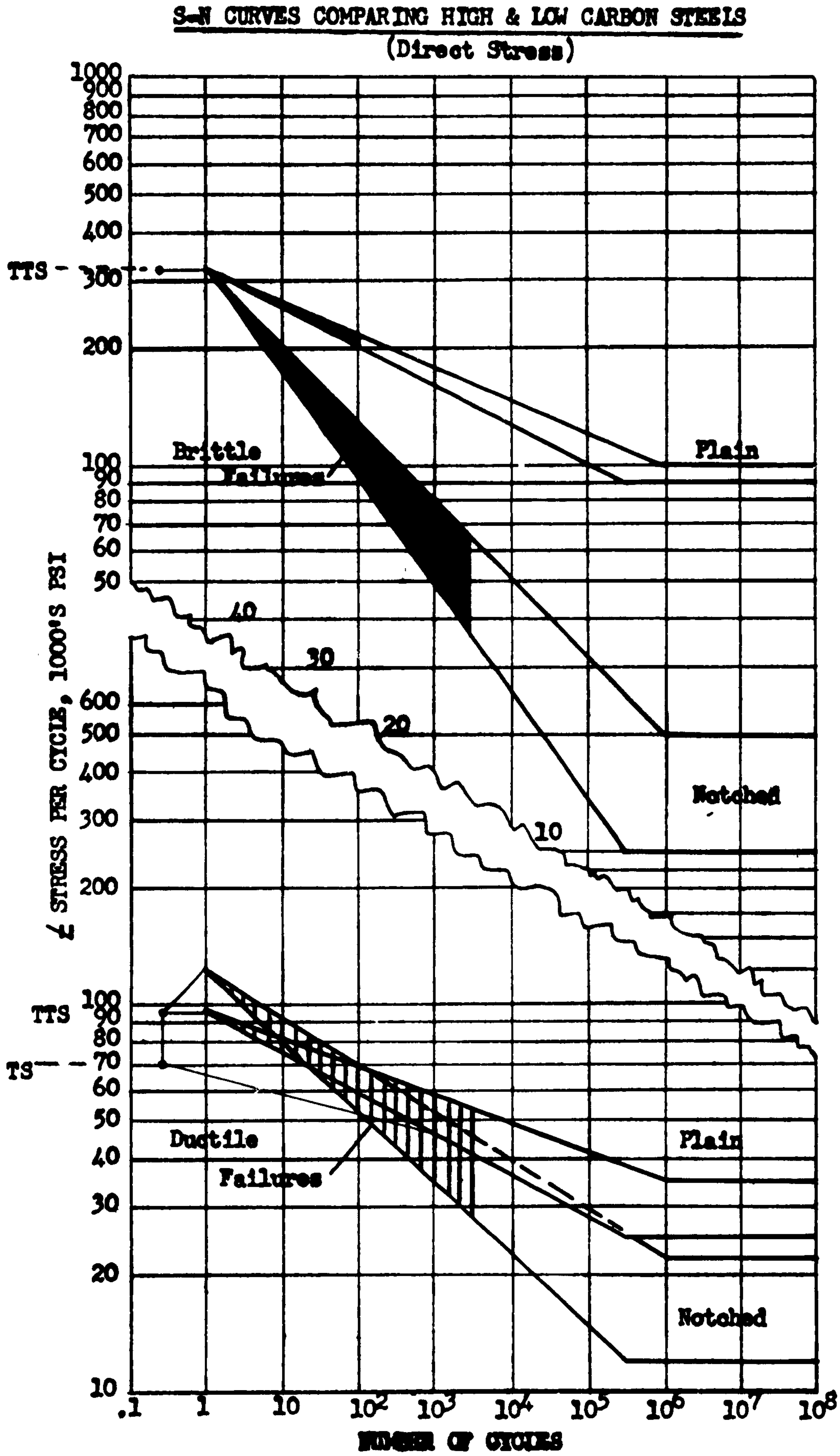




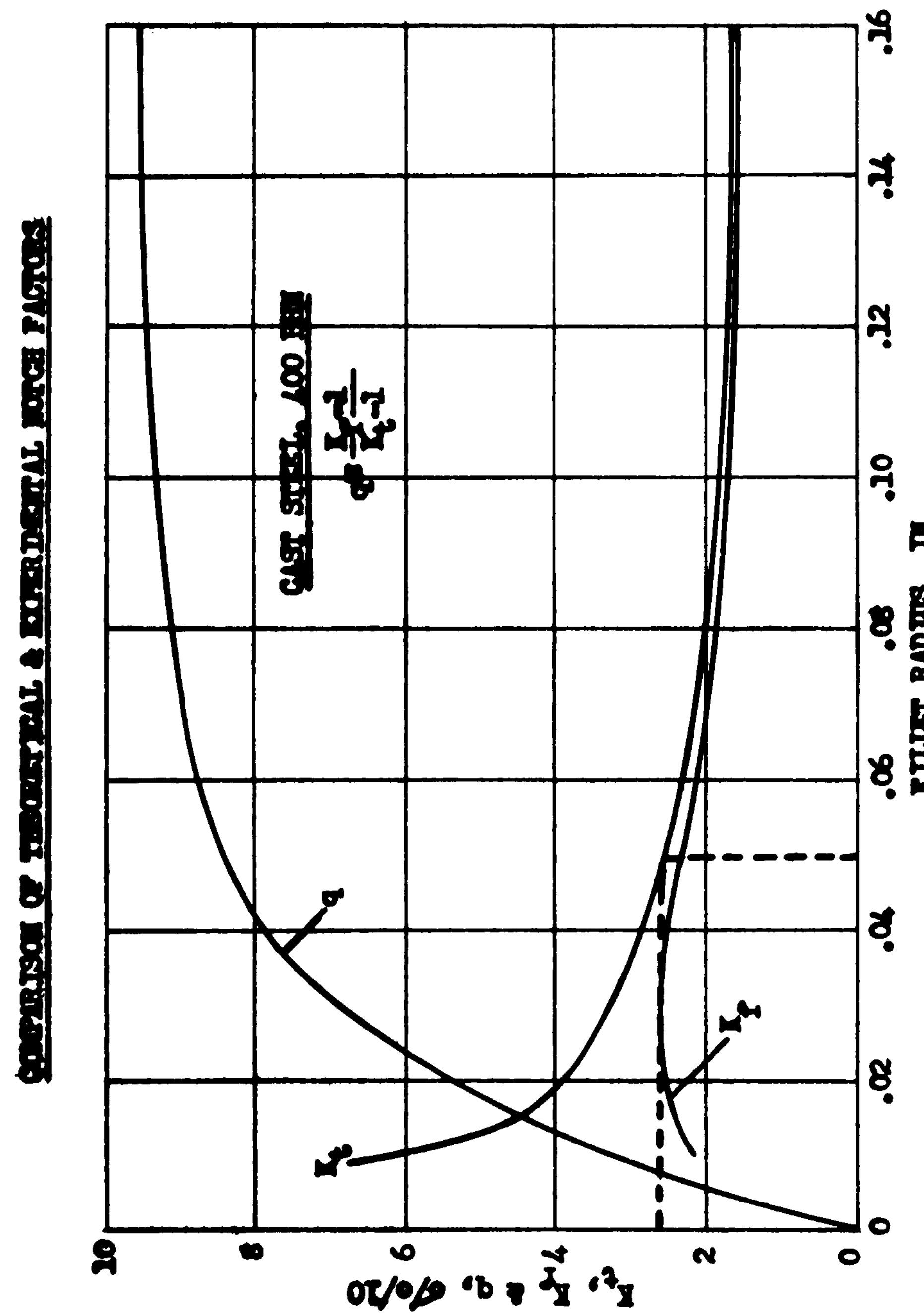
COMPARISON OF TENSILE & ENDURANCE STRENGTH, CAST STEEL
(DIRECT STRESS, REVERSED, 10^8 CYCLES)
S_e - ALLOWABLE STRESS, POLISHED SURFACE
$K_f = 5$
$K_f = \frac{S_e\ (\text{Plain})}{S_e\ (\text{Notched})}$
S_e - ALLOWABLE STRESS, NOTCHED
K_f
5
4
3
2
1
ALLOWABLE STRESS, 1000'S PSI
120
110
100
90
80
70
60
50
40
30
20
10
0
ORDINARY TENSILE STRENGTH, 1000'S PSI
60
100
140
180
220
260
300
340

S-N CURVE, CAST STEEL, 400 BHN
(Direct Stress)

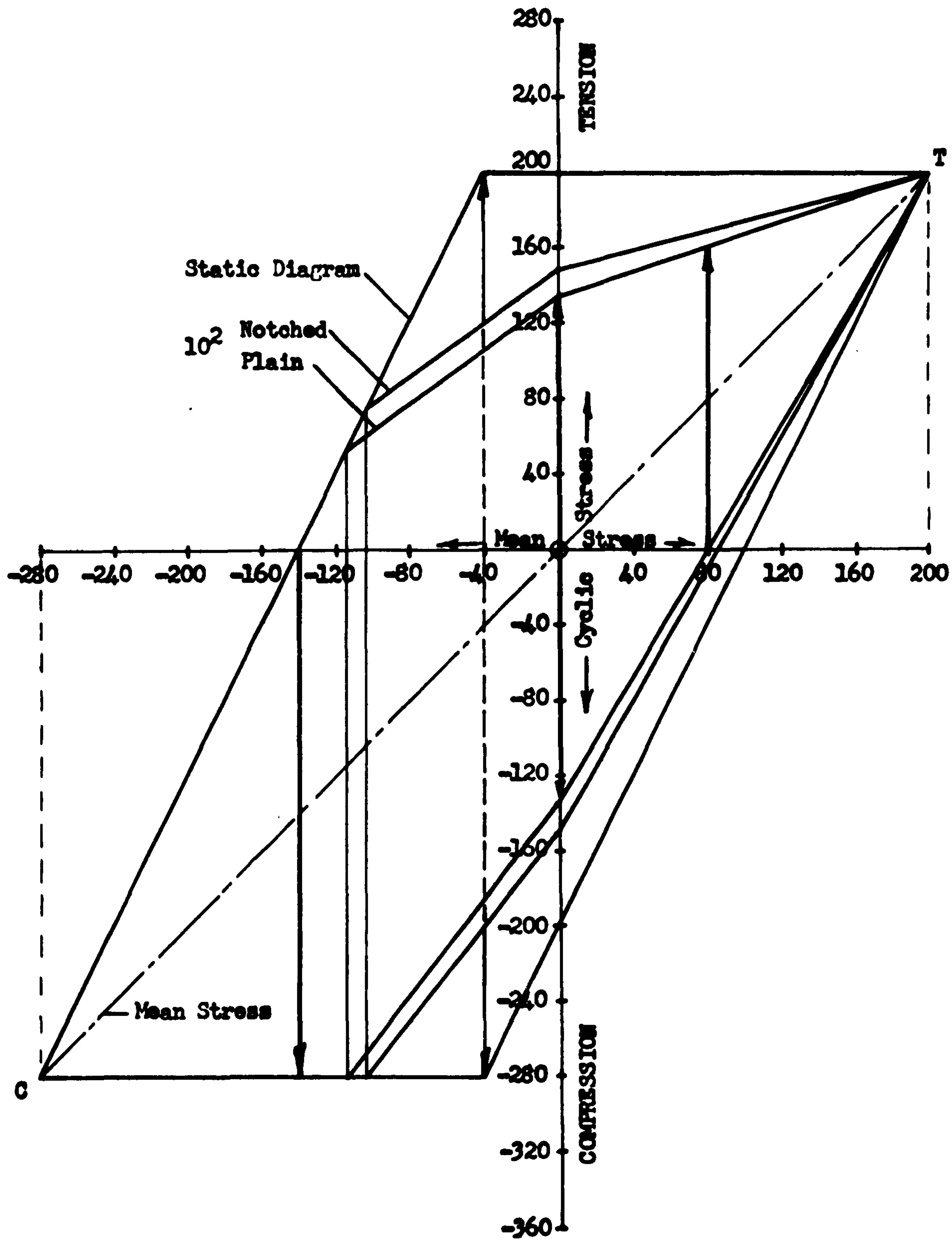




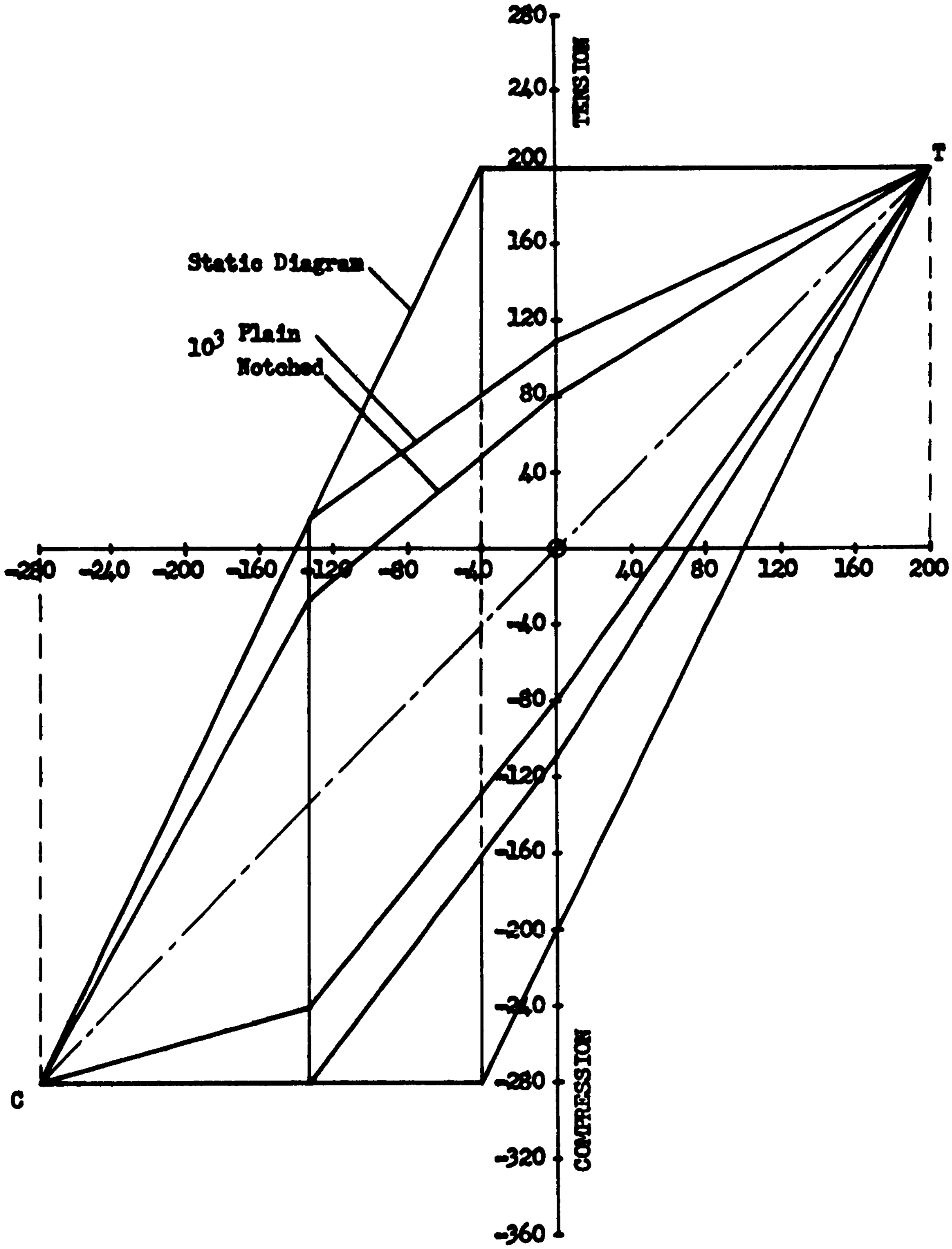
"CASTING POTENTIALS PROJECT"


COMPARISON OF THEORETICAL & EXPERIMENTAL NOTCH FACTORS
CAST STEEL, 400 BHN
q = (Kf-1)/(Kt-1)
FILLET RADIUS, IN.
Kt, Kf & q, σe/10
q
Kt
Kf
0
.02
.04
.06
.08
.10
.12
.14
.16
0
2
4
6
8
10

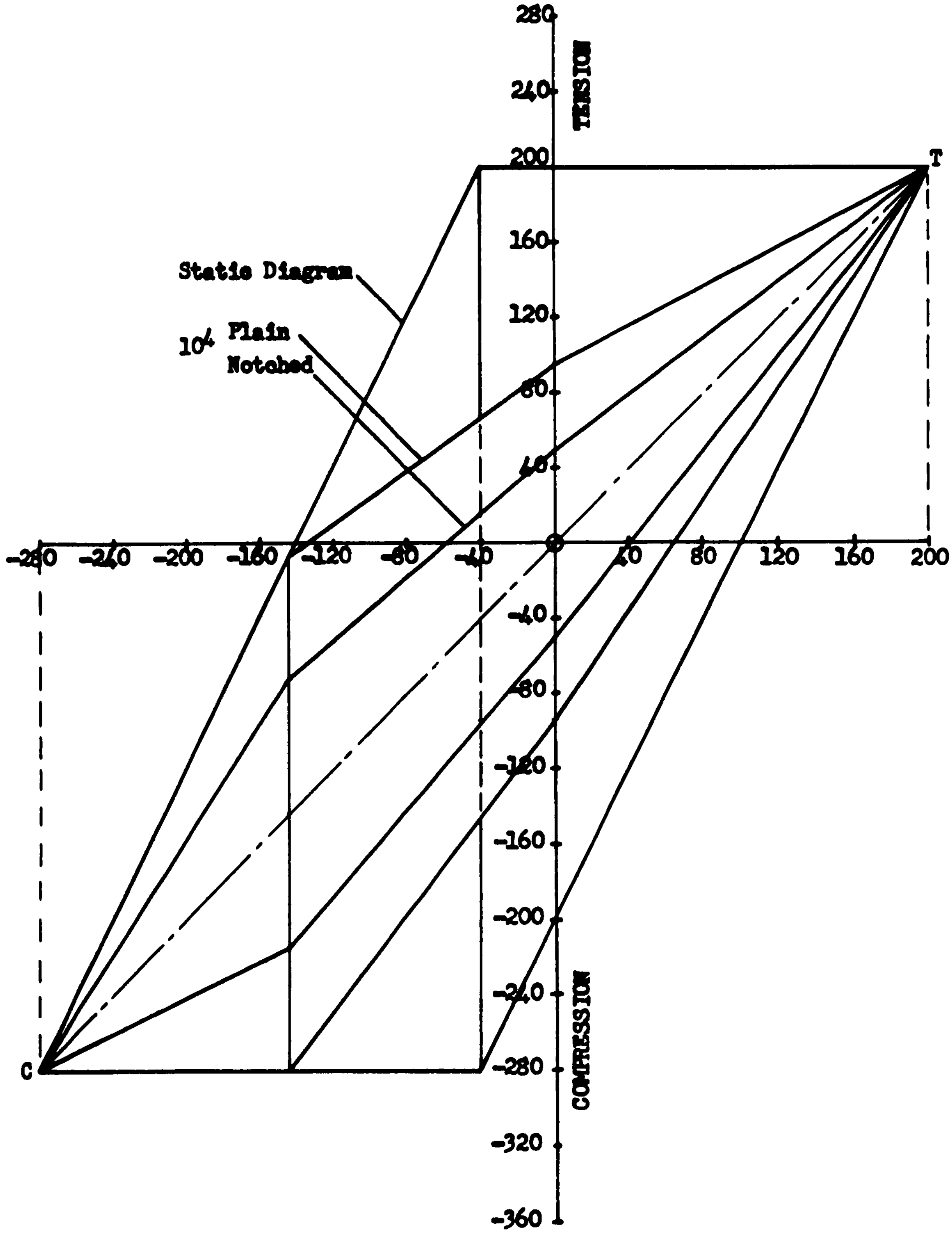
FAILURE DIAGRAM, CAST STEEL, 10^2 CYCLES



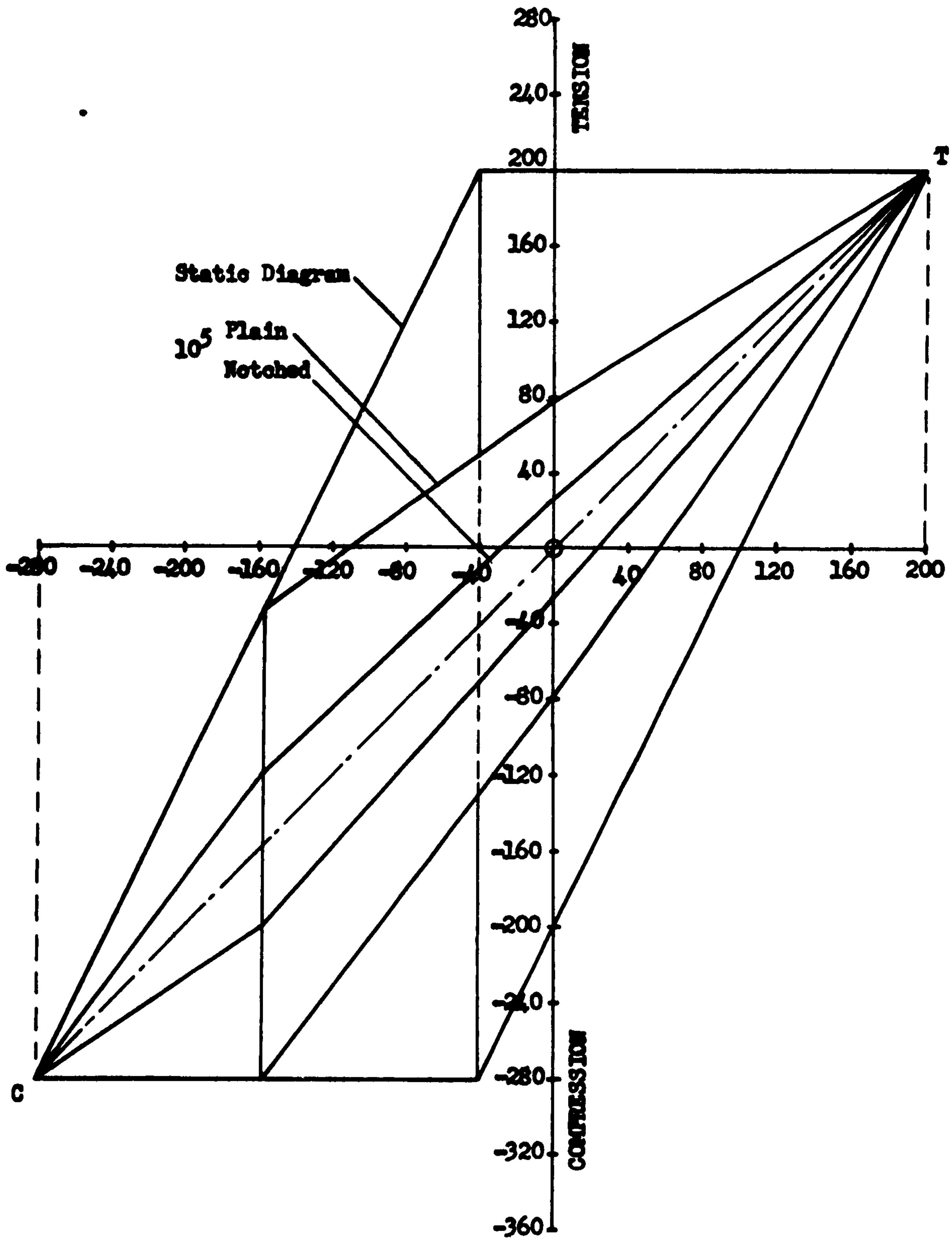
FAILURE DIAGRAM, CAST STEEL, 10^3 CYCLES



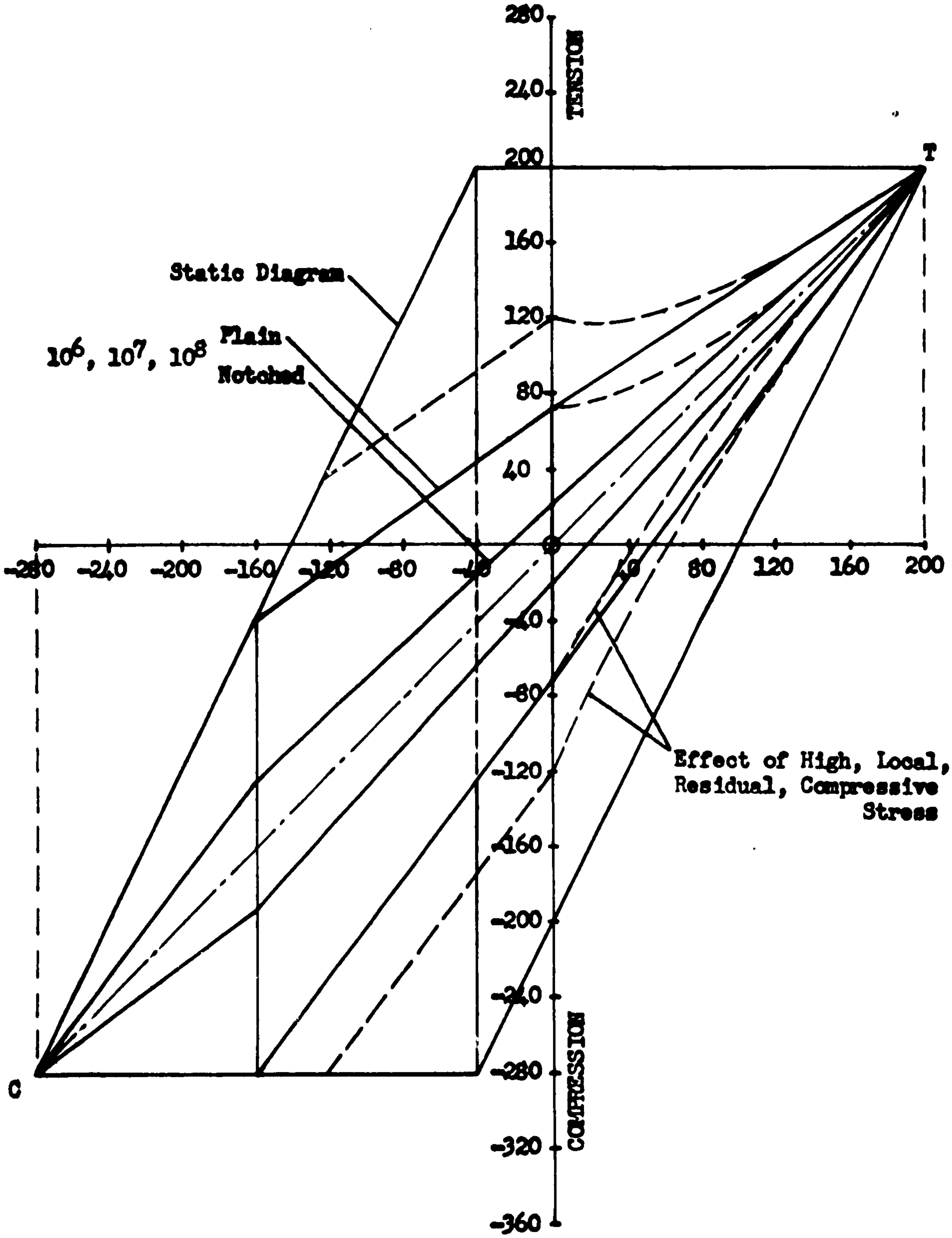
FAILURE DIAGRAM, CAST STEEL, 10^4 CYCLES

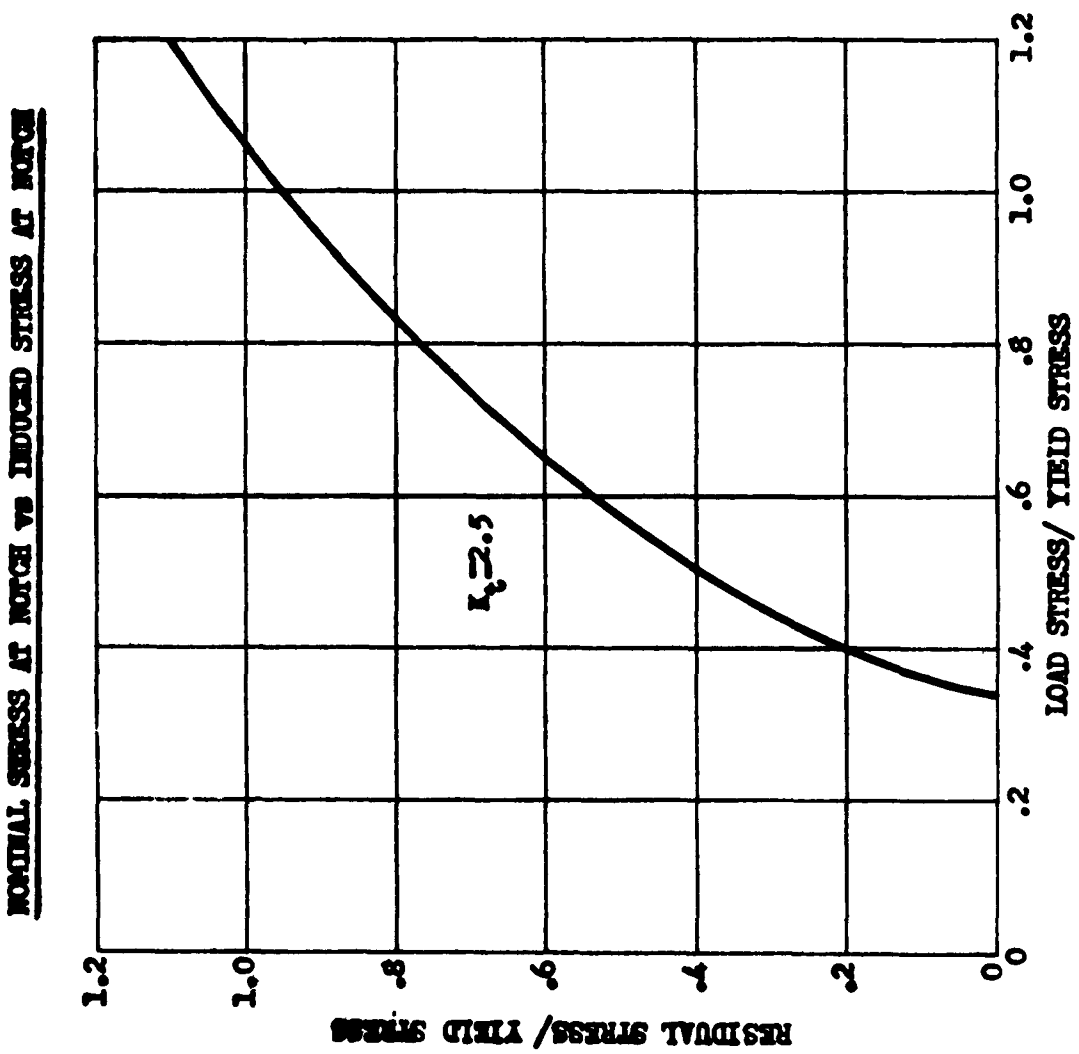


FAILURE DIAGRAM, CAST STEEL, 10^5 CYCLES



FAILURE DIAGRAM, CAST STEEL, 10^6, 10^7, 10^8 CYCLES




NOMINAL STRESS AT NOTCH vs INDUCED STRESS AT NOTCH
K_t=2.5
LOAD STRESS/ YIELD STRESS
RESIDUAL STRESS/ YIELD STRESS
0
.2
.4
.6
.8
1.0
1.2

SECTION II - CHASE 123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

D. High-Strength, Heat Treated Steel Castings Produced from above Patterns. (Work not specified in Contract.)

1. PURPOSE AND PROCEDURE

A. **PURPOSE**:

It was considered that a demonstration of (a) the producibility of subject 1/8" wall section "Tublarform" design as a high-strength alloy steel casting, and (b) the properties attainable by heat treatment of such material in such section, would be a constructive addition to this report. As such effort was not specified by the contract, it was conducted at private expense, and report was delayed to include results hereinafter reported.

B. **PROCEDURE**:

1. Army Ordnance personnel at Watertown Arsenal were considered to have unexcelled experience in the metallurgy and specialized production of high-strength alloy steels employed extensively in Ordnance materiel. Their recommended specifications as to metallurgy, melting practice, and heat-treatment of alloy steel, having physical properties in excess of properties arbitrarily employed in Contractor's design calculations, were obtained.

2. Such specifications were followed in the production of castings employing the identical wooden pattern equipment, gating and molding materials employed in the production of the H. R. alloy castings reported in Section II, Item B.

3. Subject steel castings were produced in the Boston plant of the General Alloys Company. Castability was demonstrated on first two castings poured.

4. Samples were cut from different sections of subject steel castings and, together with standard test bars, were subjected to tensile tests by an independent laboratory.

5. Photographs of castings produced, process detail and technical data, and test results are reported on two following pages.

NOTE: 1. Implement of test procedure is indicated as follows: (a) Design of improved holding chucks in testing machine for handling as-cast section specimens and for located and recorded measurement of sectional variations in samples tested. (b) Grid plotting and accurate jig. (c) Compilation and evaluation of same by formulated calculations.

2. It is believed that reduction of pouring temperatures of future castings will be beneficial.

3. Ceramic gating techniques and the composition and form of ceramic gating components employed are General Alloys Company's and Contractor's proprietary process and are subject to patents pending.

SECTION II - CHASE C-123-B MAIN LANDING GEAR DRAG LINK ATTACHMENT FITTING

D-2. Photographs of Trial Nickel-Chrome Alloy Casting and High-Strength Steel Castings Produced by General Alloys Company, Boston, Mass.

As noted on preceding page, high-strength alloy steel castings were produced by General Alloys Company in Boston from analysis and by melting procedures informally recommended by Metallurgical Engineers of Watertown Arsenal, Ordnance Corps, U.S. Army.

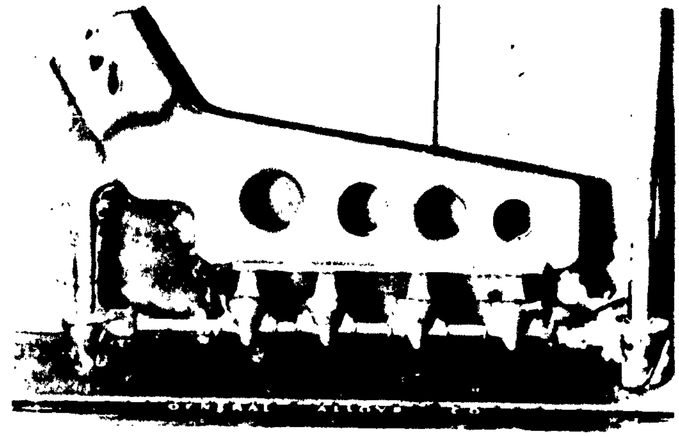


Photo #1: A test casting in 35% Ni. - 15% Cr., poured as "check".

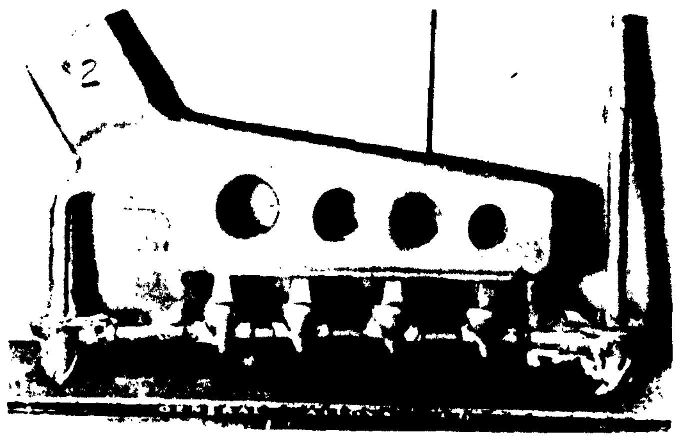


Photo #2: Alloy steel casting produced from same equipment. Metallurgy, process and test data is separately included in this report.

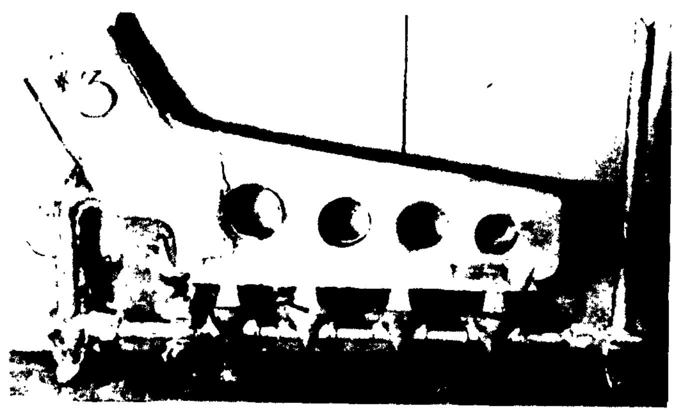


Photo #3: Second steel casting produced on same heat and scrapped. Had defects which could be repaired by welding (the vertical fin running to the left of first hold on head end is not a defect but is metal that ran into slight crack in mold. This casting was sectioned to provide samples for preliminary and concurrent heat treatment with casting, Photo #2.

Castings are shown as they came from the mold without work of any kind. Pouring temperature was higher than would be employed in production of casting by process recommended.

Castings were poured inclined at an angle of approximately 30° with head end up, thus enabling the metal to almost completely fill the mold before hot metal was fed to the head. Pouring temperature was higher than is now considered necessary as indicated by fluidity of metal in forming fins at mold partings, and in running around the outside of ceramic component at bottom of downgate.

Conclusion: X-Rays of casting showed minor shrinks at several gates which were repaired by welding. This was expected. Gating system employed was compromise in experimental sand casting, and no similar condition would result in castings by process initially and currently proposed. No shrink at centerline, or otherwise, was revealed by X-Ray except as noted. Section of #3 revealed sound metal throughout the 1/4" thick attachment end of which tapers into 1/4" section in side walls, which tapers to 1/4" section in flange.

It is indicated that this part can be produced in 1/8" or thinner sections with vastly improved dimensional control structure finish, and general natural cleanliness at materially lower pouring temperatures in ceramic molds and by contractor's centripetal casting process, employing continuous temperature and atmosphere controls. Pattern-dies and rigging of far greater accuracy and complexity than the conventional equipment employed on the above castings is essential in advanced process recommended.

TECHNICAL DATA: RE METALLURGY, PRODUCTION & HEAT TREATMENT OF HIGH STRENGTH ALLOY STEEL CASTINGS - CHASE LANDING GEAR DRAG LINK FITTING

MATERIAL

FURNACE CHARGE		FIGURED		ANALYSIS DESIRED	ACTUAL
Armco	178.00	C	0.34	0.30	0.24
Pig Iron	14.70	Si	0.40	0.25	0.61
FeMn	0.75	Mn	1.00	0.75	0.71
6%C. FeCr.	1.75	Cr	0.60	0.55	0.58
CaSi	1.25	Ni	1.50	1.50	1.67
FeMo	1.00	Mo	0.35	0.35	0.32
Ni	3.00				
Mis ch Metal	0.50				

Pouring Temperature - Casting S1 2990°, Casting S2 3000°

Final Heat Tr.

1. Anneal 1700°F. Furnace Cool (100°/hr. max.)
2. Heat to 1550°F Hold 2 hrs.
3. Quench in agitated salt bath at 500°F.
4. Cool to Room Temperature. Hold 6 hrs.
5. Temper at 450°F - Air Cool.
6. Repeat Step 5.

(Note: HT of Casting & Test Samples - Samples separately HT'd were tempered at 650°F.)

Results of Tensile Tests:

Physical Tests by Inspection Service, Little Building, Boston, Massachusetts.

Two sections, simultaneously heat treated with the complete casting, were tested by an independent commercial laboratory, "Inspection Service", Little Building, Boston, Massachusetts, May 28. A 1/4" section cut from the central portion from a flange of the "hat" section and a 1/8" section cut from the central portion of the casting. These tested respectively as follows:

Specimen No.	Yield Strength (lbs. per sq. in.)	Tensile Strength	Elongation (% of 2")
(1/4") 4	138,500	200,000	4.0
(1/8") 2	135,000	203,000	6.5

The heat treatment selected followed the recommendations of Mr. Bruce Kiner, Metallurgist of International Harvester Company, an authority in this field, obtained from his extensive experience, in cooperation with this project.

Other samples were tempered at 650°F as per Watertown Arsenal experience. (It is noted that such experience is principally with castings of ten to sixty times greater section.) Corresponding samples of 1/4" and 1/8" section tested by Inspection Service tested as follows:

Bar	Yield	Tensile	Elongation in 2"
5	154,000	157,000	2.0
3	144,500	174,500	1.0

NOTE: Figures on the first sample appear to be out of balance which is considered a probable result of the sectional and surface irregularities of this sand cast thin section which is difficult of preparation and attachment for testing.

SECTION III

CHASE C-123-B MAIN LANDING GEAR TRUNNION

Chase Part No. 8B-410020 Chase Aircraft Company, West Trenton, New Jersey

REDESIGNED FROM "I" SECTION ALUMINUM FORGING TO "TUBLARFORM" HIGH STRENGTH ALUMINUM CASTING.

THIS SECTION INCLUDES:

A. DESIGN:

1. Perspective Sketch of Comparative Designs.
2. Chase Dwg. 8B-410020 and Contractor's Dwg. CP-559.
3. Stress Analysis by Chase Aircraft Company.
4. Contractor's Design Study and Basic Stress Calculation.

B. PRODUCTION:

Experimental Production of Aluminum Castings to Provide Physical Forms for Stress Evaluations.

C. STRESS EVALUATION:

Illustrated Report of Stress Testing and Comparative Evaluation of Aluminum Forging and Aluminum Casting.

Fig. 1

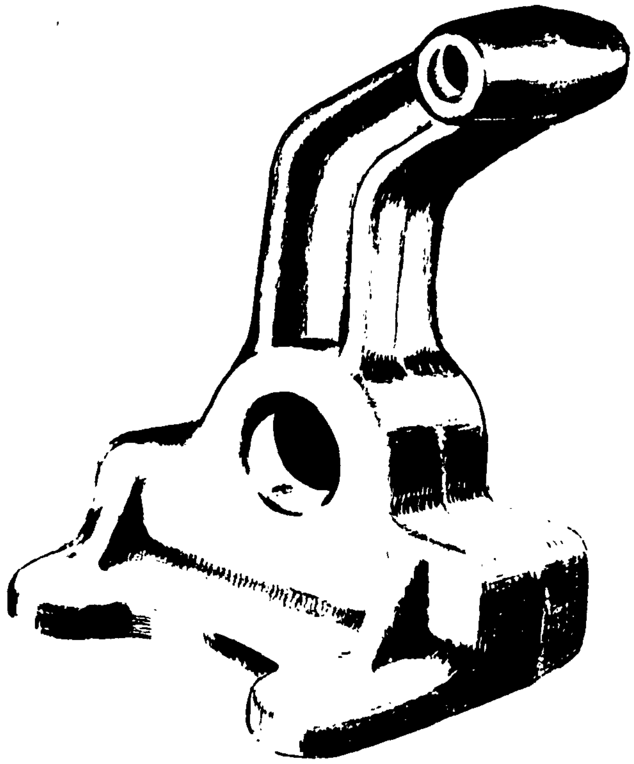
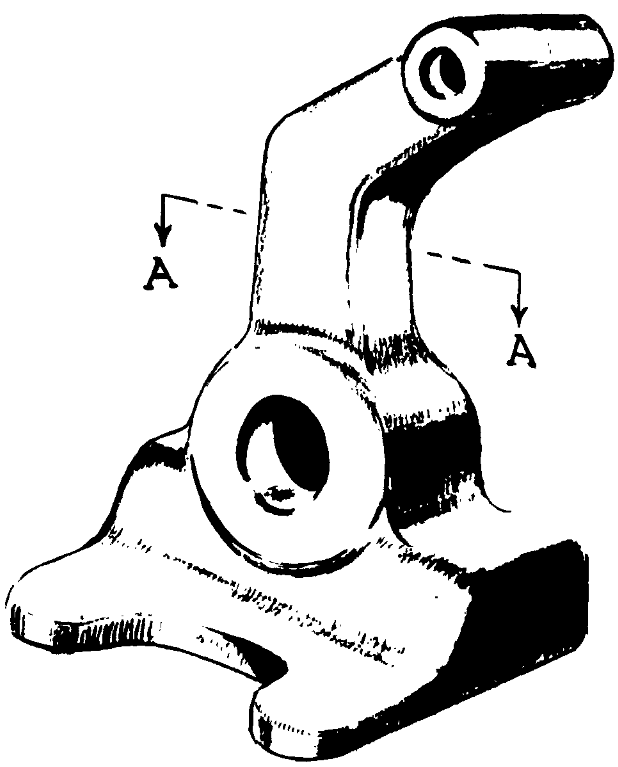
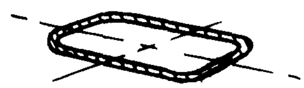


Fig. 1. Chase C-123-B Main Landing Gear Trunnion, Part #8B-410020, an "I" section aluminum forging employed in production aircraft.

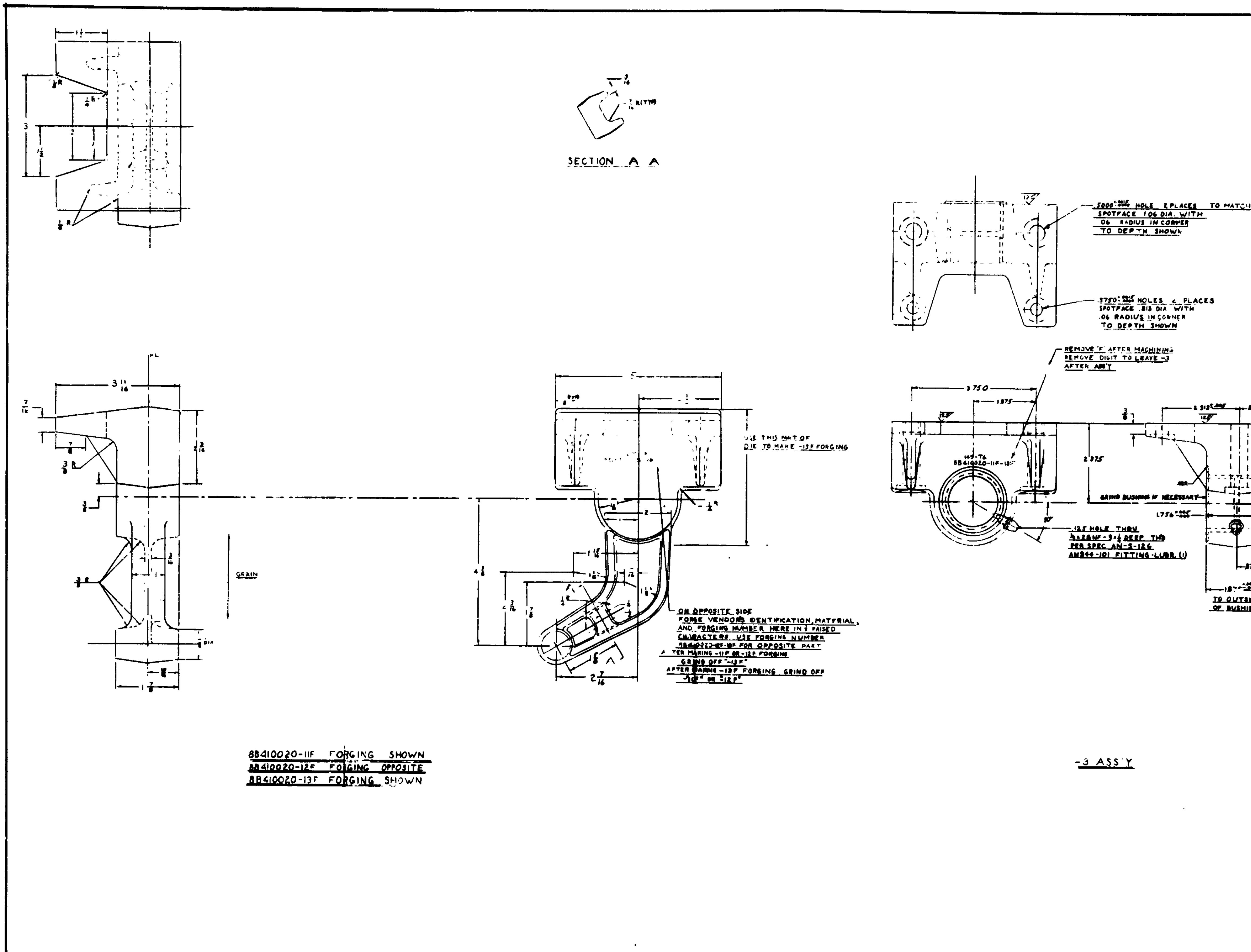
Fig. 2





Section A-A

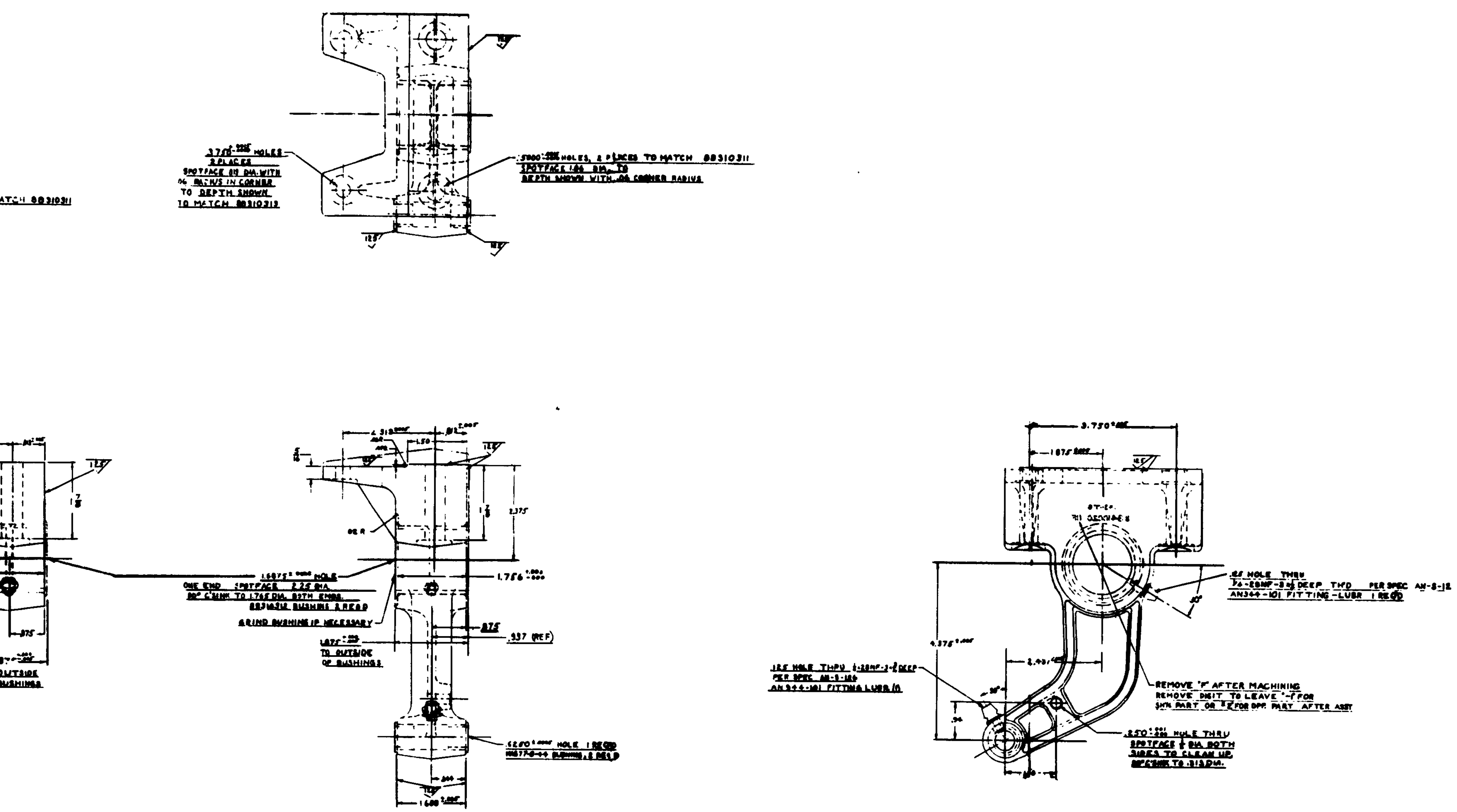
Fig. 2. Contractor's redesign of Chase Main Landing Gear Trunnion as a "tublar-form" high integrity aluminum casting with reduction in weight and superior strength-weight ratio indicated by stress analysis and stress test hereinafter reported.



CHASE AIRCRAFT COMPANY, INC. C-12

PART NO. 8B410020. Dw

MATERIAL: ALU



-1 ASS'Y SHOWN
-2 ASS'Y OPPOSITE

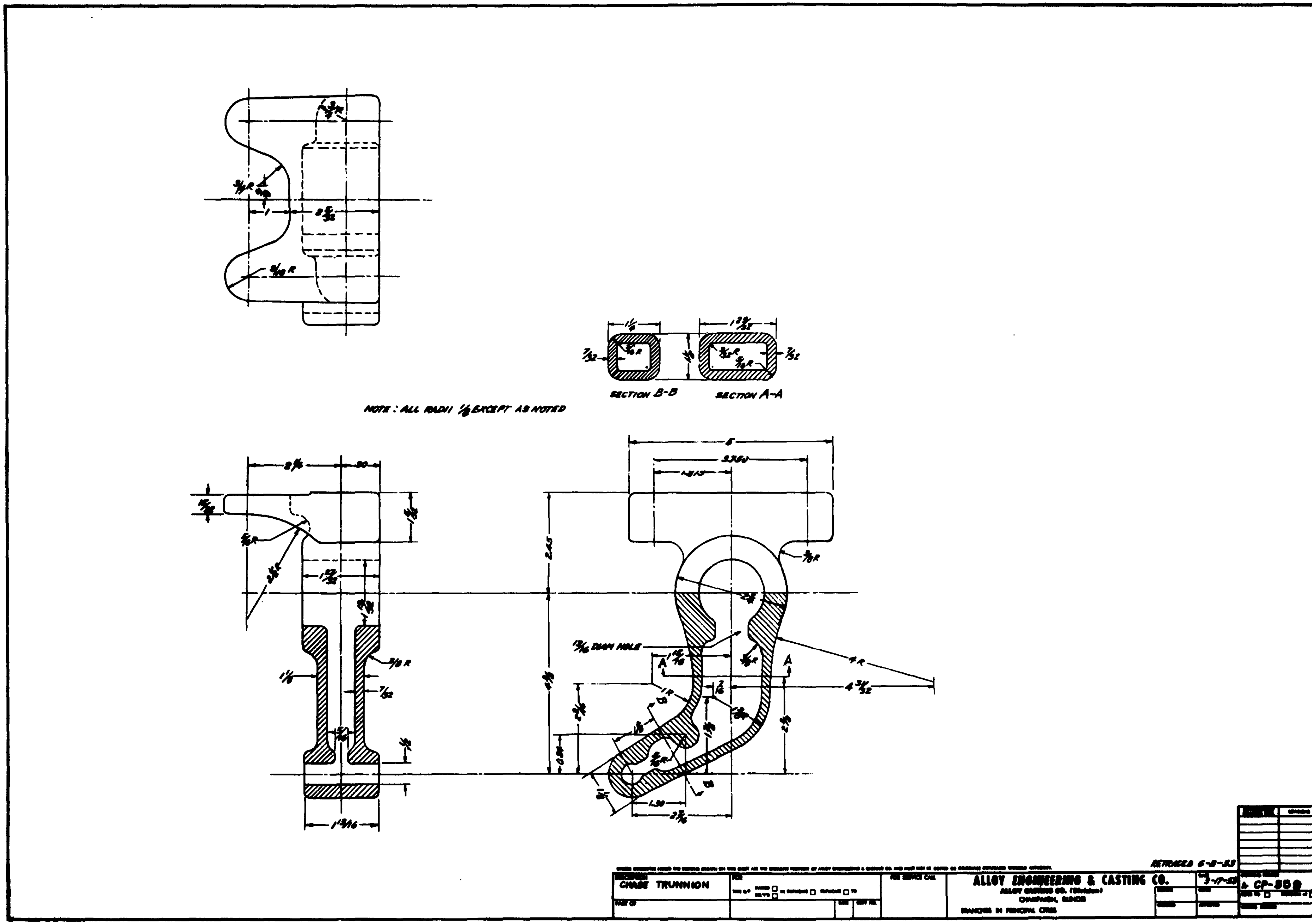
FORGING NOTES-
1. DRAFT ANGLE 7°
2. CORNER & FILLET RADII .06 UNLESS OTHERWISE SHOWN
3. REMOVE BURRS, SHARP EDGES, ETC.
4. FORGINGS TO BE STRAIGHTENED AT SOURCE
5. TOLERANCES;
 LENGTH & WIDTH: ±.03
 THICKNESS: ±.03
 MISMATCH: 0 TO .015 MAX.
 STRAIGHT WITHIN .015
 FLASH WIDTH 0 TO .03 MAX.

MACHINE NOTES:
1. MACHINE FINISH TO BE 125 RMS
2. BREAK ALL SHARP EDGES

GENERAL NOTES:
1. USE SMALLER BILLET TO FORGE -1

TRUNNION ASS'Y
MAIN LANDING GEAR
CHASE AIRCRAFT CO. Inc.
8B410020

C-123B, MAIN LANDING GEAR TRUNNION
. Dwg. NO. 8B410020.
ALUMINUM FORGING



CHASE C-123B MAIN LANDING GEAR TRUNNION
REDESIGNED AS "TUBLARFORM" HIGH-STRENGTH ALUMINUM CASTING. A.E.C.CO. Dwg NO. CP-559.
REDESIGNED FROM CHASE PART NO. SB410020, Dwg. NO. SB410020, ALUMINUM FORGING.

STRESS ANALYSIS

BY

CHASE AIRCRAFT CO., INC.

OF

MAIN GEAR TRUNNION

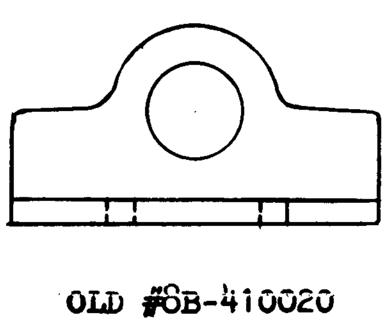
PART NO. 8B-410020

and

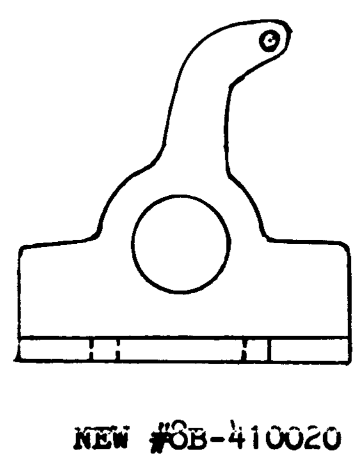
ATTACHMENT FITTING

PART NO. 8B-310300

(NOTE: "Old" Main Gear Trunnion, Part No. 8B-410020, as Herein Shown and Analyzed, was Altered in Design by Chase. The New Part, Retaining the Same Parts Number, is the Part Redesigned for Casting.)



OLD #8B-410020



NEW #8B-410020

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

Fittings analyzed in this section are listed below.

(1) Trunnion - 8B-410020
(2) Attachment Fitting - 8B-310311

Landing loads are introduced to the above fittings through the trunnion pin, (Ref. 8B-410004 and 8B-310410) and the fittings, in turn, distribute the loads to the trunnion beam for redistribution to fuselage structure.

In accordance with Chase Report 8B-217, the inboard trunnion fittings react the full side load while the inboard and outboard fittings act together in reacting the vertical and fore and aft loads.

The critical conditions and their loads are found in 8B-217, Page 659, and are reproduced below.

Two Point Maximum Strut Reaction

$$F'_{R_V} = F_{L_V} = -52{,}960 \text{ lb.}$$

$$F'_{R_D} = F_{L_D} = 3170 \text{ lb.}$$

Drift Landing

$$F'_{R_V} = F'_{L_V} = -23{,}500 \text{ lb.}$$

$$F'_{R_D} = F'_{L_D} = 1650 \text{ lb.}$$

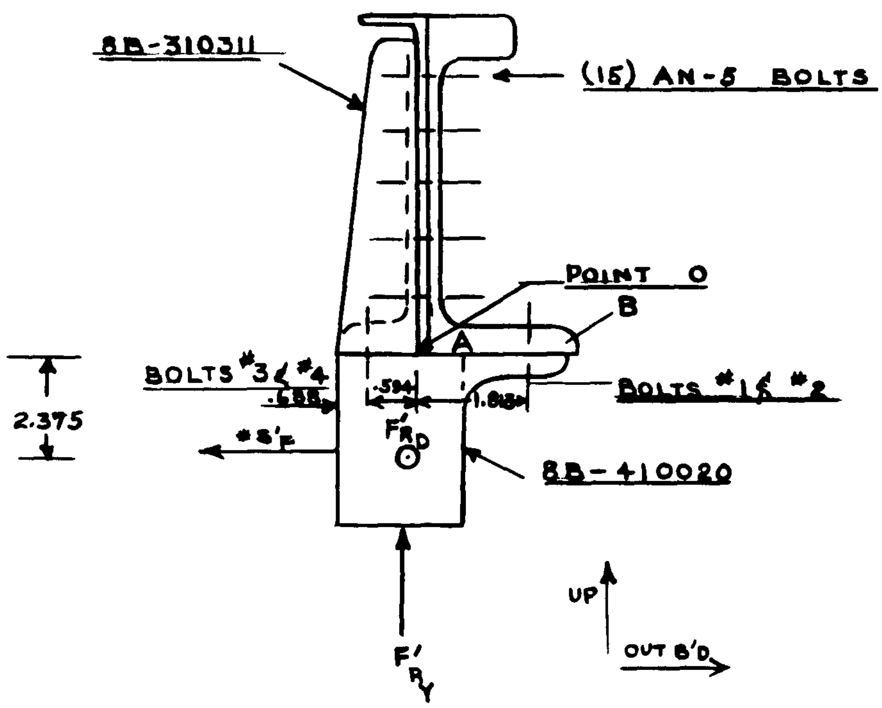
$$S'_F = -11{,}955 \text{ lb.}$$

The inboard fittings are checked for the Drift Ldg. Condition.

The outboard fittings are checked for the Two Point Maximum Strut Condition.

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

A sketch of the fittings in their assembled position is shown below.

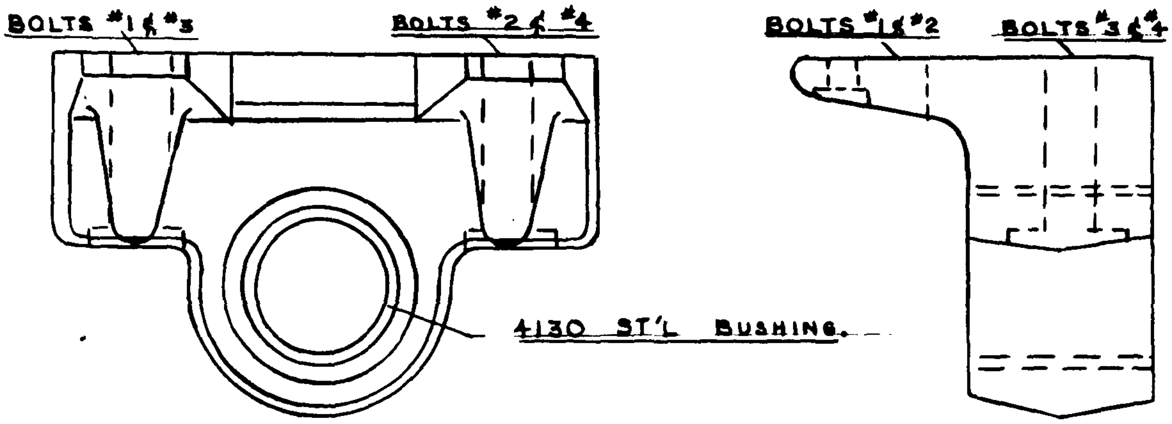


R.H.S. LOOKING FORWARD

* Inboard fittings only.

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - 8B-410020 (14S-T6 Al. Al.)



MAX LOAD ON BUSHING (4130 Steel Bar) - 8B-310312

$$P = \sqrt{(52960)^2 + (3170)^2}$$

$$P = 53000 \text{ lb.}$$

Bearing Factor = 2.0 (Ref. ANC-5; Table 2.61122)

Bearing of Trunnion Pin on Bushing.

$$f_{br} = \frac{53000 \times 2.0}{1.500 \times .812 \times 2} = 43{,}500 \text{ psi}$$

$$F_{br} = 175{,}000 \text{ psi} \quad \text{(Ref. ANC-5)}$$

$$M.S. = \frac{175{,}000}{43{,}500} - 1 = \text{LARGE}$$

Bearing of Bushing on Trunnion

$$f_{br} = \frac{53000}{1.6899 \times .812 \times 2} = 19{,}300 \text{ psi}$$

$$F_{bru} = 124{,}000 \text{ psi.} \quad \text{(Ref. ANC-5)}$$

$$M.S. = \frac{124{,}000}{19{,}300} - 1 = \text{LARGE}$$

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - 2 PT. MAX. STRUT

VERTICAL LOAD

The vertical load is distributed from the trunnion to the trunnion beam through shear in 15-AN-5 bolts and tension in 2 AN-6 bolts (bolts No.1 and No. 2) It is conservatively assumed that no load is distributed between points A and B. Summation of moments about Point "O" immediately yields the tension in bolts No. 1 and No. 2 and shear in the AN-5 bolts.

Load in Bolts No. 1, and No. 2 (Due to vertical load)

$$\Sigma M_O = F'_{R_V} (.19) - 2(1.813) P_{T_V} = 52960 (.19) - 2(1.813) P_{T_V} = 0$$

$$P_{T_V} = 2,780 \text{ lb/bolt} \quad \text{(tension)}$$

Shear Load in 15 AN-5 Bolts

$$P_{S_V} = 52,960 + 2780 = 55,740 \text{ lb.}$$

FORWARD LOAD

Bolts No. 1 and No. 3 are subjected to a tension load caused by the forward load being eccentric from the plane of the bolt pattern.

The shear induced by the direct forward load is beamed to bolts No. 1 and No. 3, and bolts No. 2 and No. 4. Additional shear in the bolts is induced because the load does not act at the bolt pattern centroid.

Tension in bolts No. 1 and No. 3

$$P_{T_F} = \frac{3170(2.375)}{3.75} = 2000 \text{ lb.}$$

Bolt No. 1

$$*P_{T_F} = 2000 \left[\frac{.1105}{(.1105 + .1964)}\right] = 720 \text{ lb.}$$

Bolt No. 3

$$*P_{T_F} = 2000 \left[\frac{.1964}{(.1105 + .1964)}\right] = 1280 \text{ lb.}$$

* Loads are apportioned according to the ratio of the shear areas of the bolts.

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

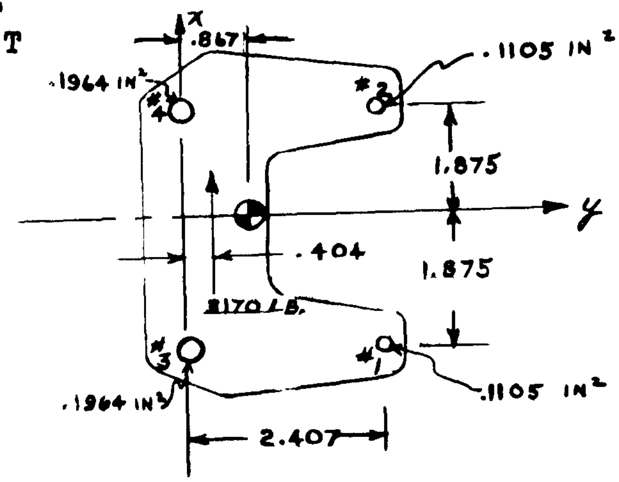
TRUNNION - 2 PT. MAX. STRUT (CONT'D.)

FORWARD LOAD (CONT'D.)

Total Bolt Tension

Maximum Tension occurs zt bolt No. 1

$$P_{T_T} = 2780 + 720 = 3500 \text{ lb.}$$



Bolt Pattern Centroid

$$\bar{x} = \frac{.1105\ (2.407)2}{2(.1105 + .1964)} = .867 \text{ in.} \qquad \bar{y} = 0$$

Direct Shear

Bolts No. 1 and No. 2

$$\left(P_{S_F}\right)_x = \frac{3170}{2}\ \frac{(.867)}{2.407} = 570 \text{ lb./bolt}$$

Bolts No. 3 and No. 4

$$\left(P_{S_F}\right)_x = \frac{3170}{2}\ \frac{(.867)}{2.407} = 1{,}015 \text{ lb./bolt}$$

Shear Due to Load Eccentricity

$$\left(P_{S_F}\right)_x = \frac{-MyA}{x^2A + y^2A} \qquad \left(P_{S_F}\right)_y = \frac{+MxA}{x^2A + y^2A} \text{ (Ref.d)}$$

$$M = 3170\ (.463) = 1468 \text{ in-lb.}$$

$$x^2A = 2(.867^2)\ (.1964) + 2(1.540)^2\ (.1105) = .8194$$

$$y^2A = 2(1.875)^2(.1105 + .1964) = 2.1579$$

SUBJECT　MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION -2 PT. MAX. STRUT (CONT'D)

FORWARD LOAD

Shear Due to Load eccentricity (Cont'd.)

Bolt No. 1

$$\left({}^{P}S_{F}\right)_y = \frac{+1468(-1.875)(.1105)}{2.9773} = -102 \text{ lb.}$$

$$\left({}^{P}S_{F}\right)_x = \frac{-1468(1.540)(.1105)}{2.9773} = -84 \text{ lb.}$$

Bolt No. 2

$$\left({}^{P}S_{F}\right)_y = \frac{+1468(1.875)(.1105)}{2.9773} = +102 \text{ lb.}$$

$$\left({}^{P}S_{F}\right)_x = \frac{-1468(1.540)(.1105)}{2.9773} = -84 \text{ lb.}$$

Bolt No. 3

$$\left({}^{P}S_{F}\right)_y = \frac{1468(-1.075)(.1904)}{2.9773} = -102 \text{ lb.}$$

$$\left({}^{P}S_{F}\right)_x = \frac{-1468(-.887)(.1904)}{2.9773} = 84 \text{ lb.}$$

Bolt No. 4

$$\left({}^{P}S_{F}\right)_y = \frac{1468(1.075)(.1904)}{2.9773} = 102 \text{ lb.}$$

$$\left({}^{P}S_{F}\right)_x = \frac{-1468(-.887)(.1904)}{2.9773} = 84 \text{ lb.}$$

Check of Bolts

Bolt No. 1 is most critical.

Tension Load = 3500 lb. (Ref. Pg. 101)

$$\text{Shear Load} = \sqrt{(570-84)^2 + (-102)^2} = 497 \text{ lb.}$$

(Ref. Pg. 101 & pg. 102)

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - 2 PT. MAX. STRUT (CONT'D.)

Check of bolts (Cont'd.)

Allow. Tension Load for AN-6 bolt in combined tension and shear = 10,000 lb. (Ref. ANC-5)

$$M.S. = \frac{10,000}{3,500} - 1 = \text{AMPLE}$$

Check of Lugs for shear-out and bearing

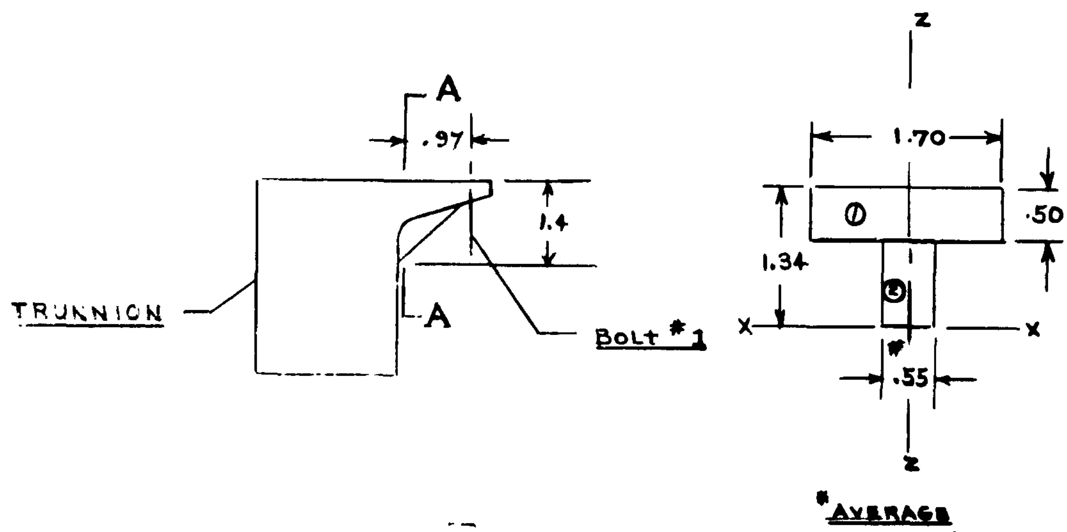
It can be readily seen that the lugs are not critical

M.S. = LARGE

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - 2Pt. MAX. STRUT (CONT'D)

Check of Trunnion
Section A-A



M_x = 3500(.97)-102(.508) = 3343 in.lb.
M_z = (486) .97 = 470 in-lb.
P_y = 102 lb.

ITEM	AREA	x	z	Ax	Az	Ax^2	Az^2	I_{ox}	I_{oz}
1	.850	0	1.09	0	.927	0	1.010	.018	.205
2	.462	0	.42	0	.194	0	.082	.027	.012
	1.312				1.121	0	1.092	.045	.217

$\bar{x} = 0$ $\bar{z}$ = .832 in.

$I_x = .045 + 1.092 - 1.312(.832)^2 = .229$ in.^{4}

$I_z = .217 + 0 - 0 = .217$ in.^{4}

$$f_b = \frac{3343(.832)}{.229} + \frac{470(.275)}{.217} + \frac{102}{1.312}$$

f_b = 12,820 psi (Tension)

F_{tu} = 65,000 psi (Ref. ANC-5)

$$M.S. = \frac{65000}{12820} - 1 = \text{LARGE}$$

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION DRIFT LANDING (SEE SKETCH ON PAGE 98)

VERTICAL LOAD

Load in bolts no. 1 and no. 2

$$M_0 = F'_{R_V} = (.19) - 2(1.813)\ P_{T_V} = 0$$

$$P_{T_V} = \frac{23500\ (.19)}{2(1.813)} = 1,230 \text{ lb/bolt (Tension)}$$

Load in 15 AN-5 bolts

$$P_{S_Y} = 23500 + 1230 = 24,730 \text{ Lb.}$$

FORWARD LOAD

Load in bolts

Tension - (Bolts No. 1 and No. 3)

$$P_{T_F} = \frac{1650(2.375)}{3.75} = 1045 \text{ Lb.}$$

Bolt No. 1

$$P_{T_F} = 1045\ \left(\frac{.1105}{.3069}\right) = 376 \text{ lb.}$$

Bolt No. 3

$$P_{T_F} = 1045\ \left(\frac{.1964}{.3069}\right) = 669 \text{ lb.}$$

Direct Shear

Bolts No. 1 and No. 2

$$P_{S_{F\,x}} = \frac{1650}{2}\ \left(\frac{.867}{2.407}\right) = 297 \text{ lb./bolt}$$

Bolts No. 3 and No. 4

$$P_{S_{F\,x}} = \frac{1650}{2}\ \left(\frac{1.540}{2.407}\right) = 528 \text{ lb./bolt}$$

CALCULATIONS ON PAGE 102, SHOW SHEARS ON BOLTS DUE TO ECCENTRICITY TO BE SMALL. SINCE THE FORWARD LOAD IS REDUCED BY APPROXIMATELY ONE-HALF, FOR THE DRIFT LANDING CONDITION., THE SHEARS DUE TO ECCENTRICITY WILL BE NEGLECTED.

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - DRIFT LANDING (CONT'D.)

SIDE LOAD

Side load reactions were determined in Chase Report 8B-217, page 155 and are reproduced below.

$R_{W.L.7} = 15,510$ lb. (inboard)

$R_{W.L.\ 15} = 3,555$ lb. (outboard)

The above reactions indicate that bolts No. 1, No. 2, No. 3, and No. 4 are loaded in shear. Loads are apportioned to each bolt according to the ratios of the shear areas.

Area of Bolts No. 1 and No. 2 = .1105 In.^{2}/bolt

Area of Bolts No. 3 and No. 4 = .1964 In.^{2}/bolt

Total Area of Bolts = .6138 in.

Shear Load on Bolts No. 1 and No. 2

$$P_{S_{SY}} = \frac{15,510}{2}\left(\frac{.2210}{.6138}\right) = 2800 \text{ lb./bolt}$$

Shear Load on Bolts No. 3 and No. 4

$$P_{S_{SY}} = \frac{15,510}{2}\left(\frac{.3928}{.6138}\right) = 4960 \text{ lb/bolt}$$

PREP. T.T.B. ON 12-8-52
CHKD. N. HESS ON 12-17-52
REVISED

CHASE AIRCRAFT CO., INC.
WEST TRENTON, N. J.

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

SUMMARY OF BOLT LOADS

2 POINT MAXIMUM STRUT									
	VERT. LOAD					FORWARD LOAD			
	NO. 1	NO. 2	No. 3	No. 4		No. 1	No. 2	No. 3	No. 4
P_T	2780	2780	**	**	P_{T_F}	720	1280	1280	**
P_{S_X}	0	0	0	0	P_{S_X}	486	486	1099	1099
P_{S_Y}	0	0	0	0	P_{S_Y}	-102	102	-182	182

DRIFT LANDING									
	VERT. LOAD					FORWARD LOAD			
	No. 1	No. 2	No. 3	No. 4		No. 1	No. 2	No. 3	No. 4
P_T	1230	1230	**	**	P_T	376	**	669	**
P_{S_X}	0	0	0	0	P_{S_X}	297	297	528	528
P_{S_Y}	0	0	0	0	P_{S_Y}	*	*	*	*

DRIFT LANDING				
	SIDE LOAD			
	No. 1	No. 2	No. 3	No. 4
P_T	0	0	0	0
P_{S_X}	0	0	0	0
P_{S_Y}	2800	2800	4960	4960

SIGN CONVENTION:-
Tension = (+)
Shear
Forward = (+)
Outboard = (+-)
Up = (+)

** Loads taken out in bearing of one fitting on another
* Ref. page 105

SUBJECT MAIN GEAR TRUNNION AND ATTACHMENT FITTING

TRUNNION - DRIFT LANDING

Check of Bolts

Investigation shows bolt No. 4 to be critical in shear.

$$\text{Shear Load} = \sqrt{(520)^2 + (4980)^2} = 4995 \text{ lb.}$$

$$\text{Allowable Load} = 14{,}700 \text{ lb.}$$

$$M.S. = \frac{14700}{4995} - 1 = \text{AMPLE}$$

Check of Lugs (Bolt No. 1)

Bearing

$$P_{br} = \sqrt{(297)^2 + (2000)^2} = 2020 \text{ lb.}$$

$$f_{br} = \frac{2020}{.375 \times .3125} = 24{,}000 \text{ psi}$$

$$F_{br} = 90{,}000 \text{ psi} \quad (\text{Ref. ANC-5})$$

$$M.S. = \frac{90{,}000}{24{,}000} - 1 = \text{LARGE}$$

Shear-Out

$$P_s = 2020 \text{ lb.}$$

$$f_s = \frac{2020}{2(.30)(.3125)} = 12{,}500 \text{ psi}$$

$$F_{su} = 35{,}000 \text{ psi} \quad (\text{Ref. ANC-5})$$

$$M.S. = \frac{35{,}000}{12{,}500} - 1 = \text{LARGE}$$

Check of Trunnion

LOADS ON BOLT NO. 1 ARE SMALLER FOR THE DRIFT LANDING CONDITION THAN FOR THE 2 PT. MAX. STRUT CONDITION.

A-4. CONTRACTOR'S DESIGN STUDY AND BASIC STRESS CALCULATION: Re Redesign of Subject Component from "I" Section Aluminum Forging to "Tublarform" High-Strength Aluminum Casting.

A. MATERIAL SELECTION: The original design of this Main Landing Gear Trunnion Assembly was produced as a 14ST-6 aluminum forging, Section III-A-3. The mechanical properties of this material are as follows: Tensile Strength 65,000, Yield Strength 55,000 and elongation 10%. Casting alloys to meet these physical properties are not commercially available. However, a review of the stress analysis of this part indicated that the margin of safety in the Trunnion Assembly was high. A reduction in mechanical properties was, therefore, permissible.

Since a load strength of the "I" section was not available from Chase, any reduction in material strength should be compensated for by increase in cross-sectional area and section modulus at this section. It was the belief of the Contractor that sufficient excess metal was present in other areas of the forged design to allow for this local increase in section without increasing the weight of the component.

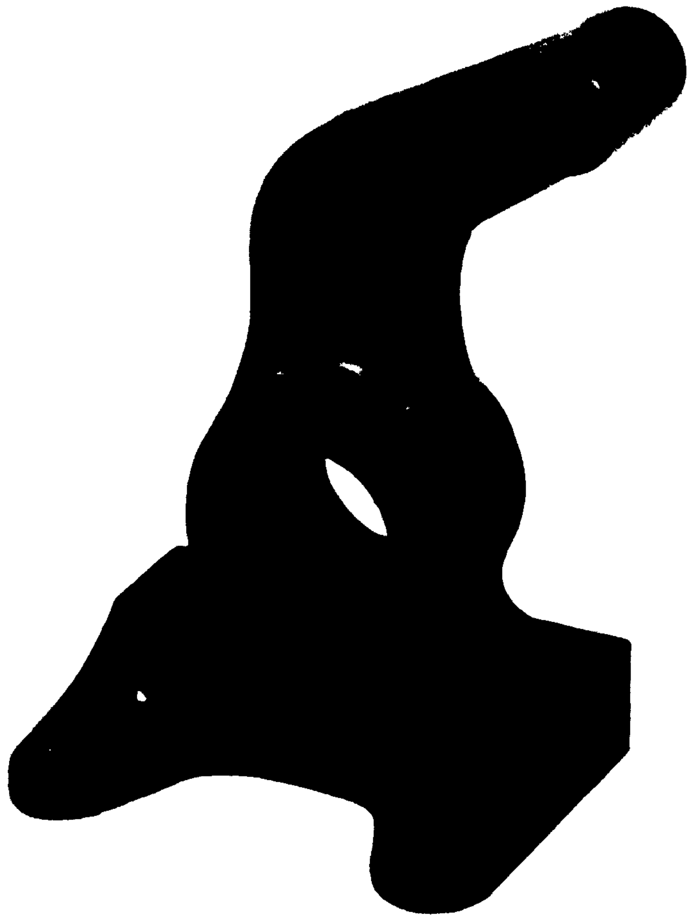
The material selected for the cast design was a 10% Mg-Al alloy similar in composition to 220. Test bar data indicated the following mechanical properties: Tensile Strength 55,000, Yield Strength 48,000, elongation 5%. Test bars cast from 75 ST were tested and higher tensile values were obtained, but lack of ductility precluded its use.

B. STRUCTURAL SHAPE: A "tublarform" (in this case a "box-beam") design was selected as the best structural shape for this casting. A plastic and clay model was constructed. Calculations were made to establish the wall thickness (at the box section) necessary to maintain a beam strength equivalent to the "I" section of the forging. The casting design is shown, Dwg. No. CP-559 (Section III-A-3).

Disadvantages in casting process and in heat treatment of the irregular masses are minimized within limits of the configuration and loading. The gross sectional irregularity is accepted because: (a) the heavy mass, being concentrated at one end, can be easily "fed" in casting, and (b) it is held securely by fastenings to solid structure, thus having a minimum of flexure. The localized sacrifice in structure (large grain size with less ductility and related fatigue resistance) is considered to involve no hazard.

On the forged part, the added mass and distribution of metal mandatory to provide "draft" in process is not productive of proportional strength-weight advantage. Small mass and excess weight involved in this small part may not justify the machining operations quite generally employed to remove this "draft penalty" metal from forging. Draft in casting is from zero to two degrees, depending on form and size, as compared with normal seven degree draft on forgings.

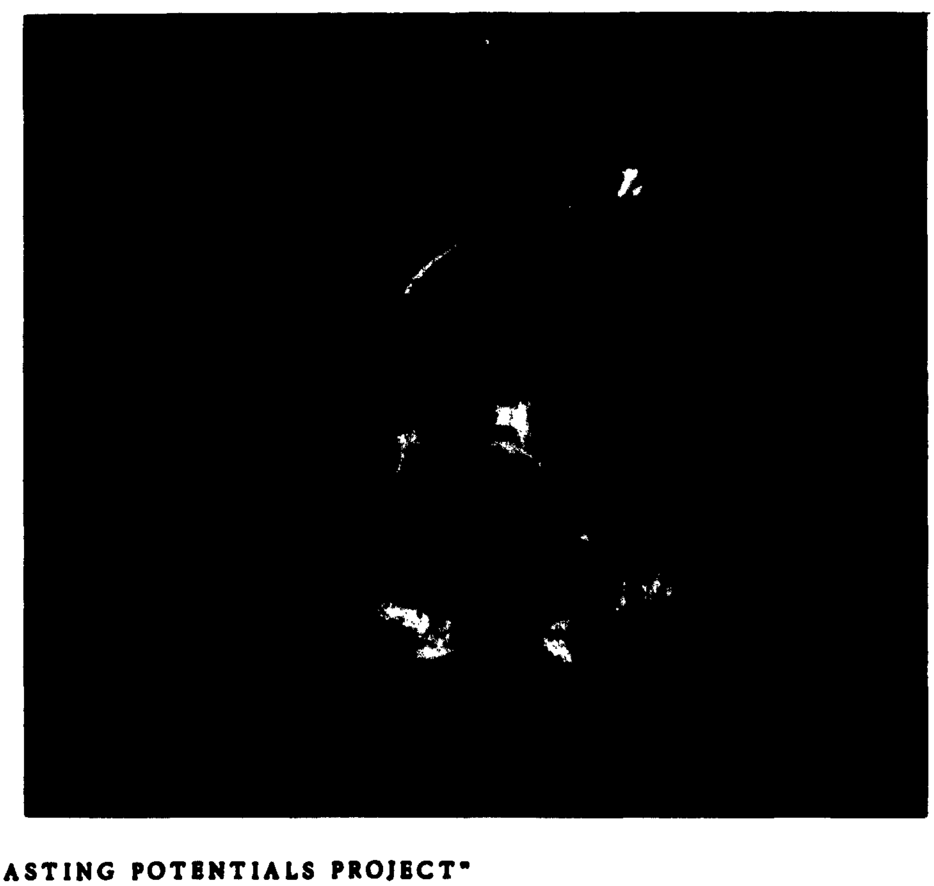
CHASE MAIN LANDING GEAR TRUNNION



PRECISION

FULL SCALE WOOD MODEL

DWG. CP-559



FULL SCALE

PLASTIC AND CLAY MODEL

OF

PROPOSED ALUMINUM CASTING

FIG. 11

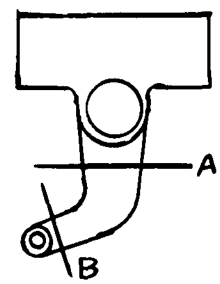
Section III - A-4 (continued)

An accurate full-scale model was made in order to simplify production of pattern equipment (by duplicating machine directly from the model). The model was parted on center line of beam in order to show core details. Experimental molds and cores were produced by utilizing this model as a master pattern.

Evaluation of form and function indicate that this part, with some design modification, might hold some promise for production as a high integrity steel casting employing a conservative figure of 170,000 psi T. S. for the steel casting.

SET "A"

CHASE TRUNNION CALC.



Determine wall thickness of box section casting necessary to produce equivalent strength of I Section forging.

S_c = 55,000 psi = T.S. of casting

S_f = 65,000 psi = T.S. of forging

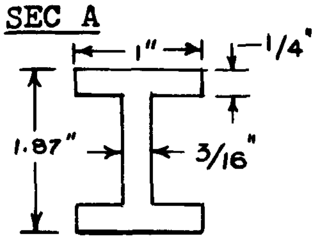
$M_c = M_f \qquad M = Z\,S \qquad S_c = .846\,S_f$

$Z_c\,S_c = Z_f\,S_f$

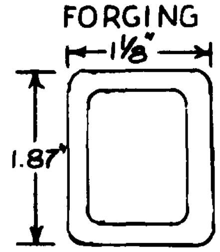
$Z_c\,.846\,S_f = Z_f\,S_f$

$Z_c = \dfrac{Z_f}{.846} = 1.18\,Z_f$

SEC A



FORGING



CASTING

$Z_f = \dfrac{1 \times (1.87)^3 - 1.373(1-.19)}{6 \times 1.87} = .397 \leftarrow Z_f$

$Z_c = 1.18 \times .397 = .468 \leftarrow Z_c$

Use $\frac{7}{32}$ Wall

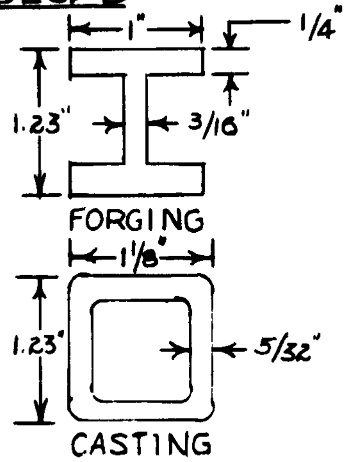
$Z_c = \dfrac{1.125\,(1.87)^3 - .69(1.43)^3}{6 \times 1.87} = .475 \leftarrow Z_c$

USE

CP-560

SET "A"

SEC. B



$$Z_f = \frac{1 \times (1.23)^3 - .75^3(1-.19)}{6 \times 1.23} = .206 \leftarrow Z_f$$

$$Z_c = 1.18 \times .206 = .244 \leftarrow Z_c \text{ NEEDED}$$

$$Z_c = \frac{1.123\ (1.23)^3 - .67\ (.79)^3}{6 \times 1.23} = .237 \leftarrow$$

SEC A CROSS SEC AREA

FORGE $(1 \times .25)2 + (1.375 \times .19) = .76 \text{ in}^2$

CAST $(1.125 \times .22)2 + (.69 \times .22)2 = .799 \text{ in}^2$

CP-560

SECTION III - CHASE C-123-B MAIN LANDING GEAR TRUNNION

B. PRODUCTION: Experimental Production of Aluminum Castings to Provide Physical Forms for Stress Evaluations.

Aluminum castings (10% Mg-Al, similar to 220) were produced by proprietary process, - (currently in volume production), - to provide physical forms for stress evaluations. Semi-ceramic molds were produced from precision full scale model to expedite production which was adequate for purpose. Metal pattern-dies are in process of production and a number of castings will be produced, - beyond this contracted effort reported, - to indicate dimensional control and finish attained by subject proprietary process. Different conventional and experimental analyses will be cast. Sections cut from castings will be evaluated to determine properties in relation to chemistry-structure and metal section. Results of such tests (apart from contract) completed will be reported.

NOTES:

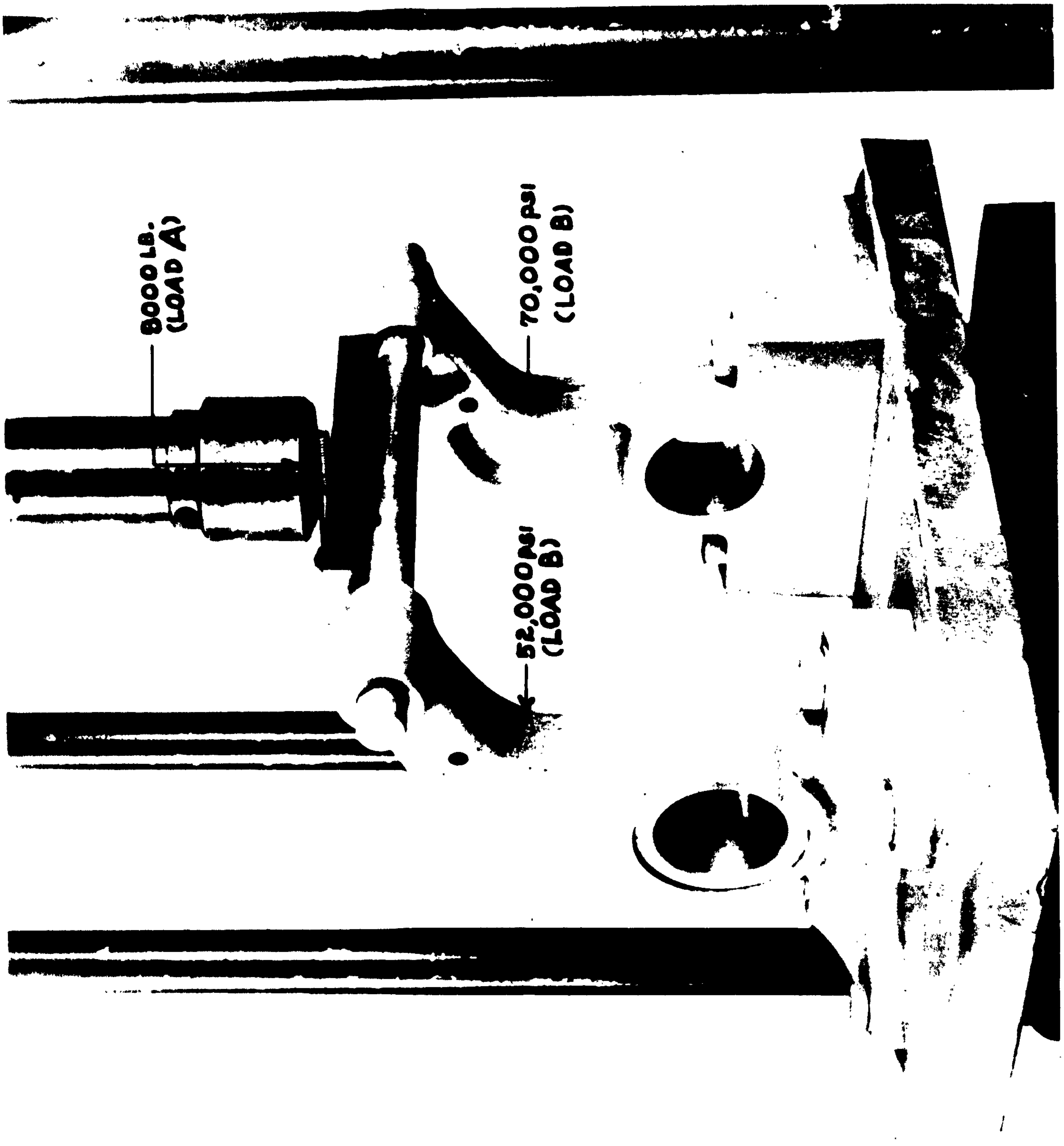
1. Results of tests on aluminum alloy test bars experimentally cast by proprietary process employed for production of subject castings, and tested by Detroit Testing Laboratories, were reported by Contractor to AMC in March 1952, maximum results being: Analysis - Cu 4.37%, Si .15%, Fe .34%, Mg 1.35%, Mn .83%; T. S. 67,000; Y. S. (02% set) 50,500; E. L. 18%; R. A. 25-7%; B. H. N. - 500 Kg LD 119.

2. Experimental production of castings of subject part, for evaluation, is continuing as noted. Basic problems are uniformity of raw material and, particularly, degree of exterior oxidation on ingot prior to melting and elimination thereof.

3. TEST BAR DATA NOT RELIABLY APPLICABLE TO CASTINGS: Standard test bars and all types of tensile test bars currently employed are considered as "rubber yardsticks". They do not reliably indicate factual properties of sections cut from castings. See reference to specifications and test material, Conclusions, Section V.

4. An as yet indeterminate effort is indicated as necessary to determine the attainability of physical properties in aluminum castings to equal or exceed the test bar values as reported (Note #1). Continuation of such effort is included in the Recommendations, Section V.

CHASE MAIN LANDING GEAR TRUNNION
T EST FIXTURE TO COMPARE FORGED AND CAST DESIGNS (LOAD A)



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 12

SECTION III - CHASE C-123-B MAIN LANDING GEAR TRUNNION

C. - STRESS EVALUATION -- Illustrated Report of Stress Testing and Comparative Evaluation of Aluminum Forging and Aluminum Casting.

Note: Photos, Numbered 12 to 18 inclusive, and Charts, Numbered 16 to 22 inclusive, are attached in numerical sequence, as referred to in text.

1. Laboratory Procedure:

An experimental stress analysis was conducted in order to compare the stress distribution of the cast design with the forged design. Both designs were stress-coated and subjected to identical load conditions.

A vertical load of 8,000 lbs., Load "A", was applied, as shown in Fig. 12, in order to evaluate stress distribution in the beam section. Load "B", Fig. 13, was identical to Load "A", but opposite in direction. Load "C", Fig. 14, was applied to each design in order to evaluate the stress distribution in the bearing area of the trunnion. The bending moment produced by this load was much higher than would be encountered in normal operation, but was used to compare continuity at this part of the structure.

The components were subjected to incremental loads, prior to the final load application. Areas of high stress concentration were circled at each incremental loading, Fig. 15 and 16.

SR-4 strain gages were installed in these areas in order to obtain significant stresses. Small gage lengths were employed where necessary. The strain indications produced by Load "A" were noted, Fig. 15 and 16, but were considered of little importance due to their low values. The maximum stresses from Load "B" occurred at Point "X" in the forging and Point "Y" in the casting.

Fig. 17 and 18 show the stress distribution in the forging and casting respectively for load application "C".

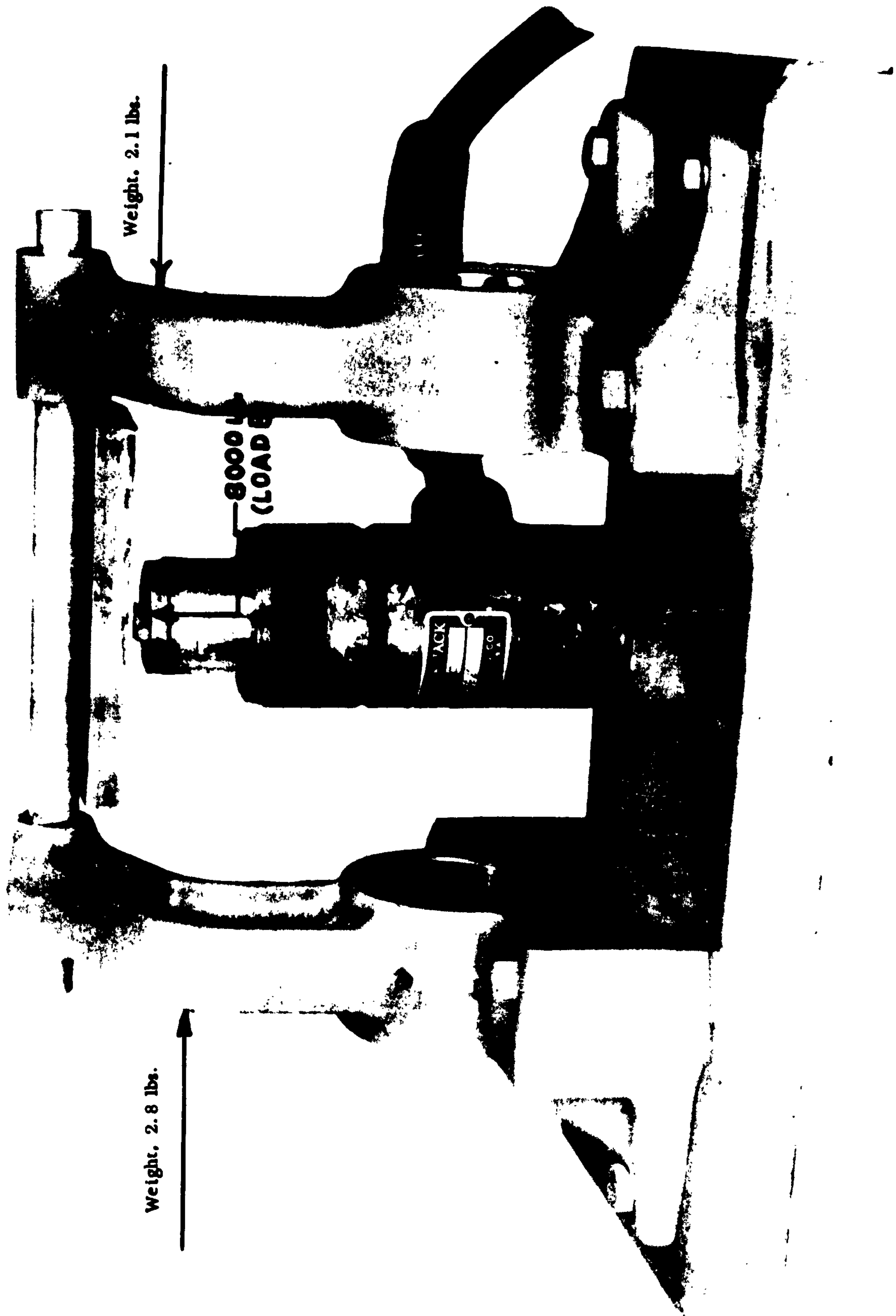
2. Static Strength:

True stress-strain curves for various aluminum alloys are shown in Curve No. 16. Based on the true tensile strength, the margin of safety in the forging at Point "X" was: M.S.=80/70 - 1=0.14. Similarly, for the casting, it was: M.S.=63/52 - 1 =0.21. Therefore, the casting design achieved a higher margin of safety than the forging in the beam section. However, Load "C" indicated that the forging was superior to the casting design.

3. Recommended Design Changes:

In order to increase resistance to Load "C" by improving the continuity of the

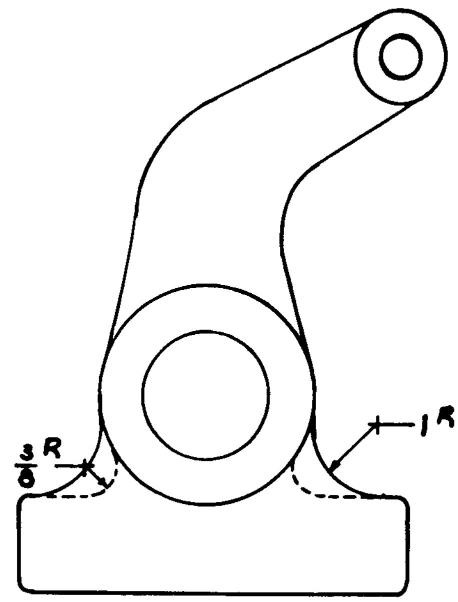
CHASE MAIN LANDING GEAR TRUNNION
COMPARISON OF FORGED AND CAST DESIGNS (LOAD B)



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 13

casting at this section, a design change is in order (Figure right). It is believed that comparable margins of safety from Load "C" can be obtained in this manner. The weight of the modified casting would be increased from 2.1 to 2.2 lbs. The weight reduction of the new casting (based on the forging) would be 21%.



4. Endurance Strength:

S/N curves for the forged and cast materials are shown in Curves No. 17 and 18. Curve No. 19 compares the endurance strength of the forged material, notched, with the un-notched cast material.

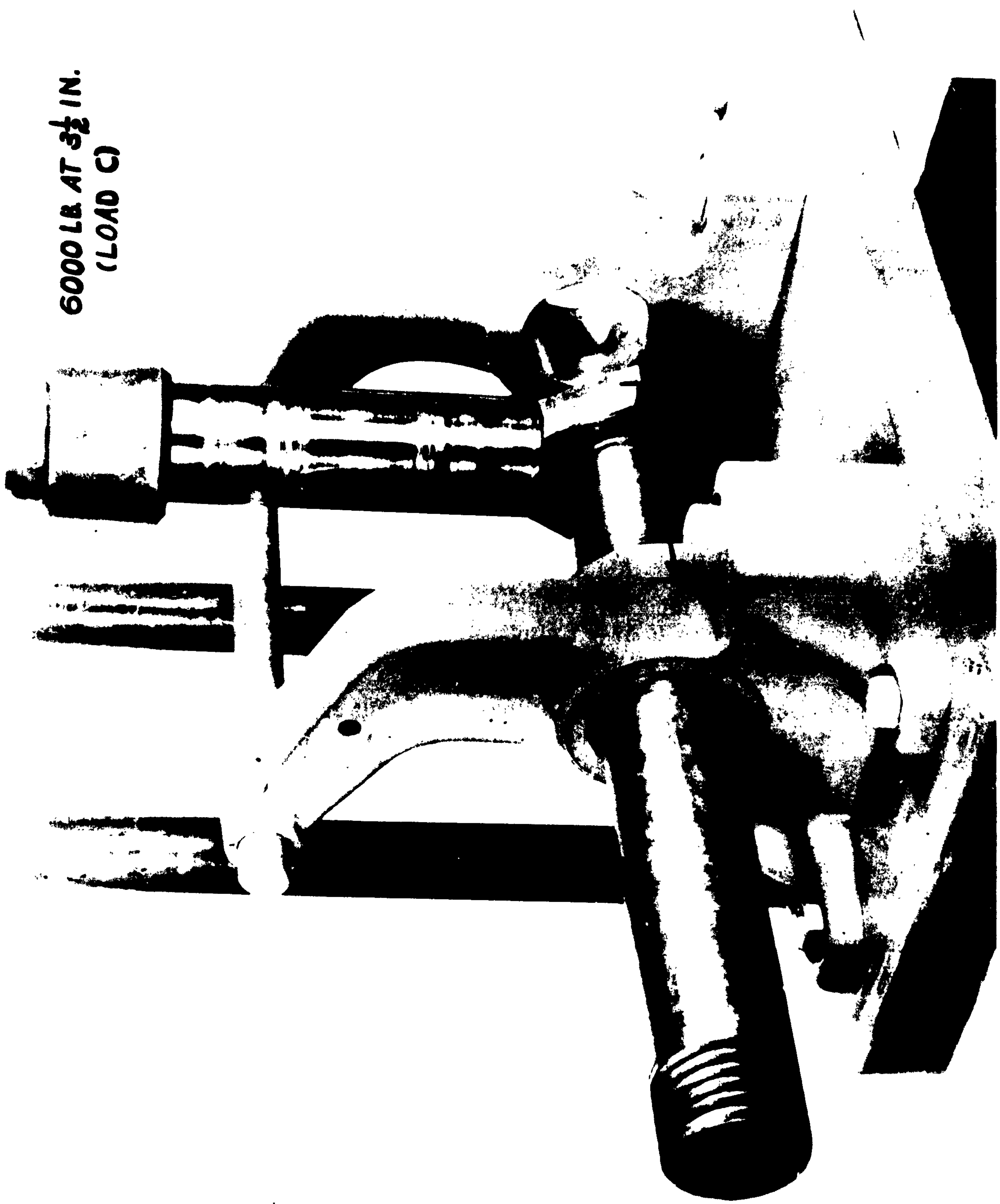
This curve indicates that in order to meet the endurance strength of the forged design, careful attention must be given to achieve good stress distribution by avoiding all abrupt changes in section. Or, stated in another way, the casting, in order to have a comparable endurance life with the forging, must achieve better structural efficiency. The casting process allows this to be done. It is important to note that forged aluminum designs produced as aluminum castings (with properties commercially available) will experience a reduction in endurance strength and static strength as well, Curve 19. (Indications of needed improvement in casting elongation is projected in Recommendations of this Report.)

In order to offset the apparent reduction in static strength necessitated by the reduction in tensile strength of the cast material, an increase in sectional area is necessary, unless a design can be effected which will result in higher structural efficiency.

Strength reduction notch factors for aluminum are given in Curve No. 20. It will be noted that the critical fillet radius for this material is 0.10 in. Failure diagrams for forged and cast aluminum are shown, Curves No. 21 and 22. Critical loading conditions for the trunnion fitting must be established before endurance life can be established.

Note: Curves employed reflect extensive experience with aluminum castings produced by conventional practice. Comparable experience with castings produced by advanced process is not, as yet, available for comparative evaluation.

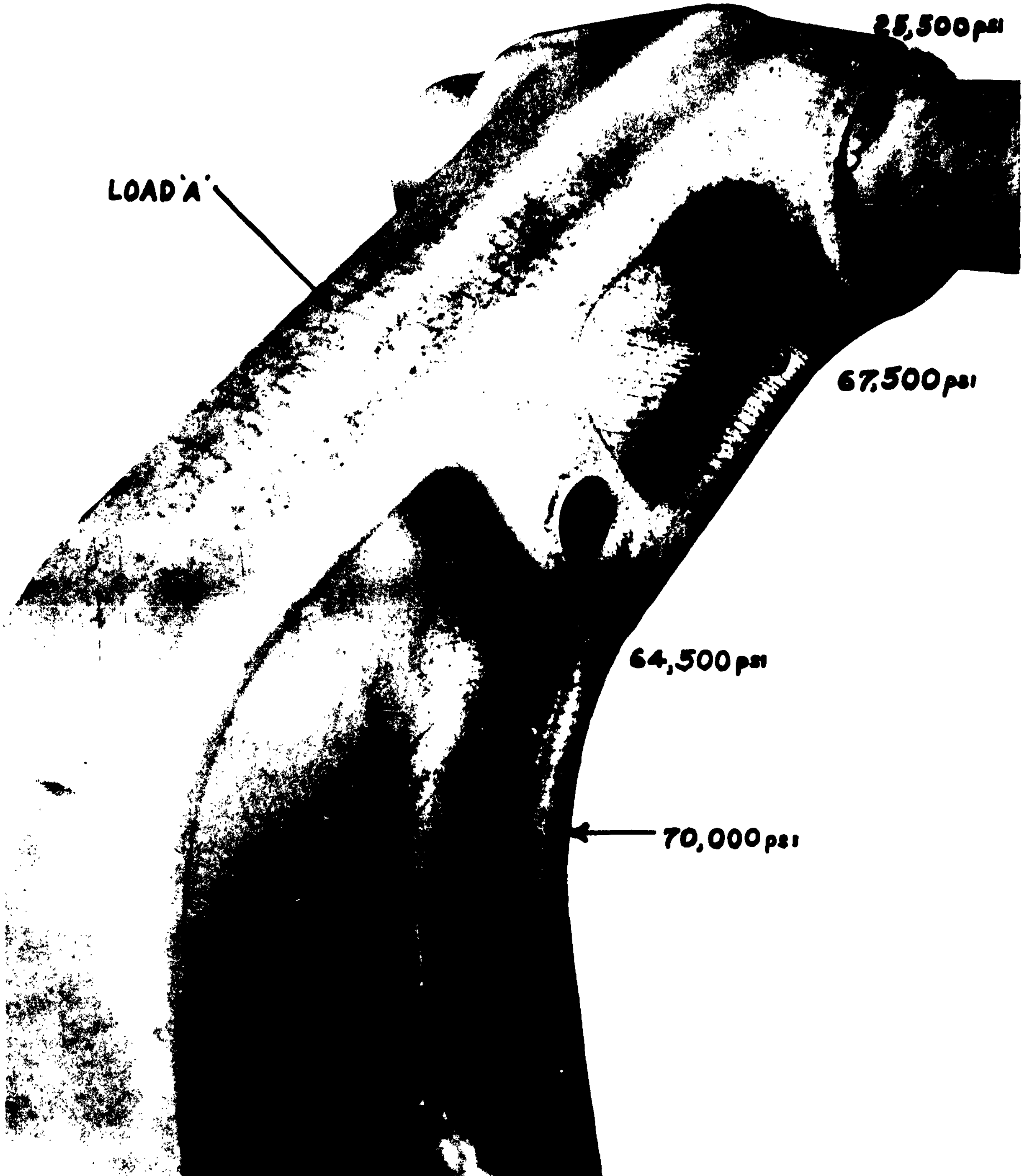
CHASE MAIN LANDING GEAR TRUNNION
TEST SET-UP -- (LOAD C)



"CASTING POTENTIALS PROJECT"

CHASE MAIN LANDING GEAR TRUNNION

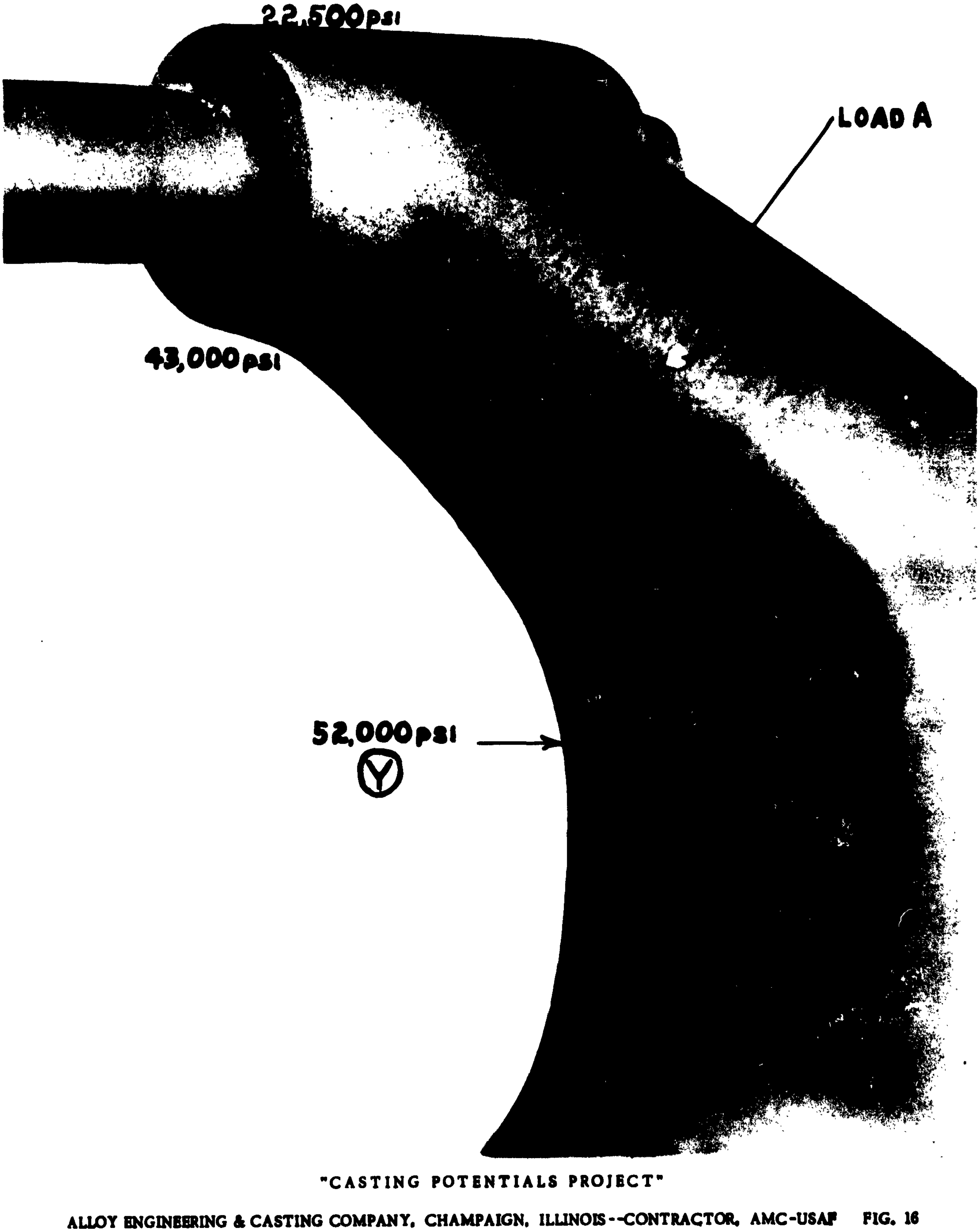
STRESS DISTRIBUTION IN "I" SECTION OF FORGING--LOAD B



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 15

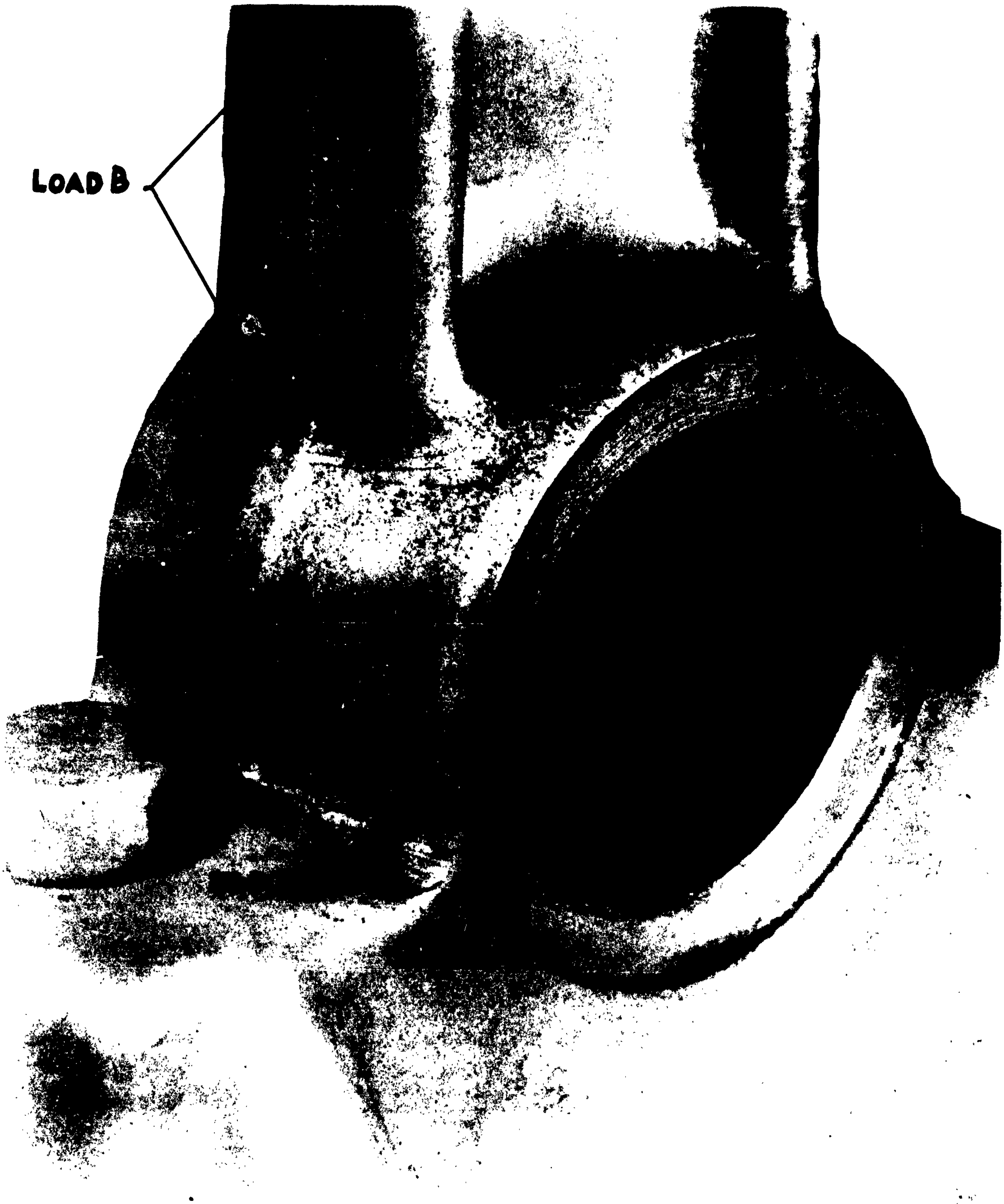
CHASE MAIN LANDING GEAR TRUNNION
STRESS DISTRIBUTION IN BOX SECTION OF CASTING--LOAD B



"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 16

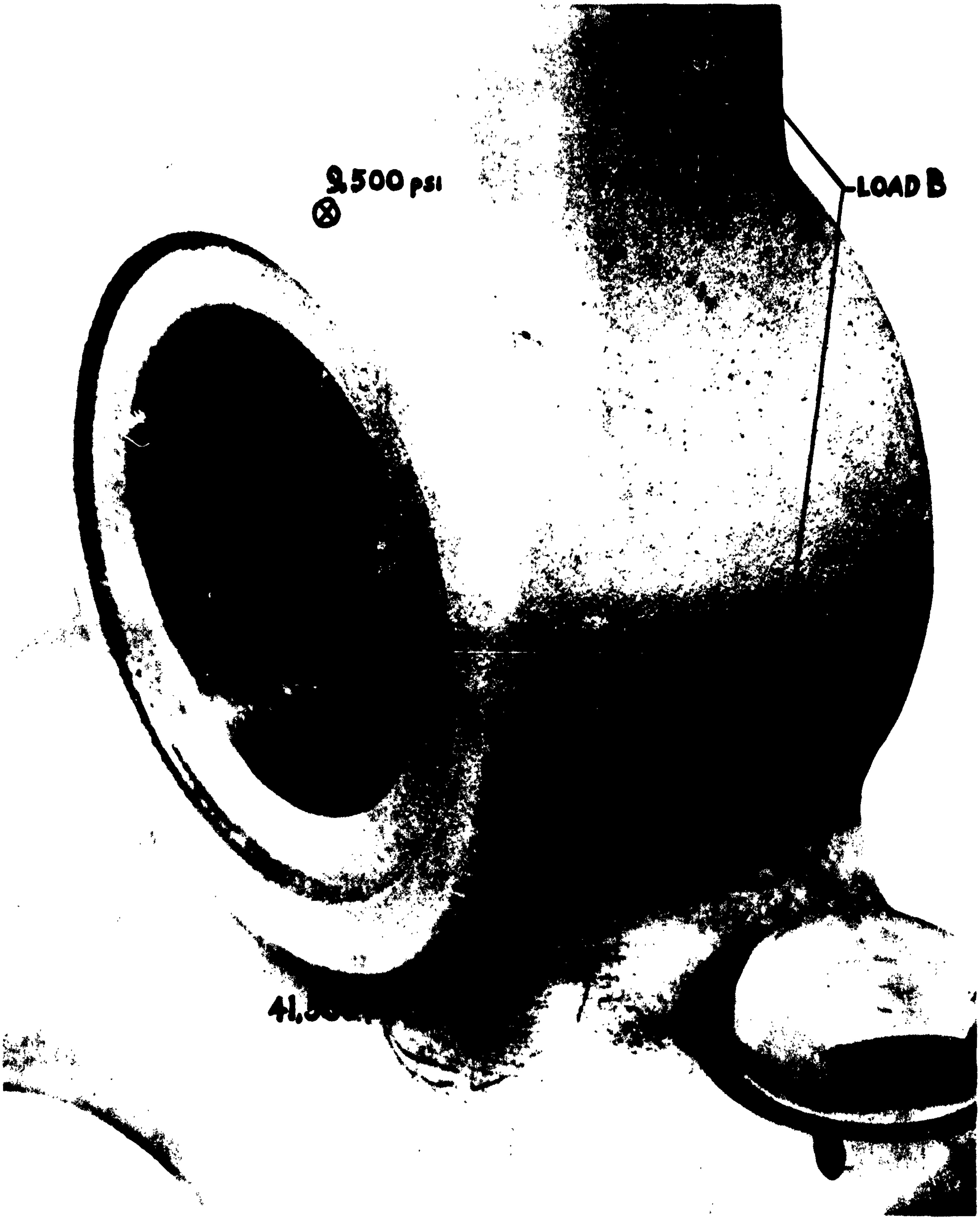
CHASE MAIN LANDING GEAR TRUNNION
STRESS DISTRIBUTION IN FORGING--LOAD C



"CASTING POTENTIALS PROJECT"

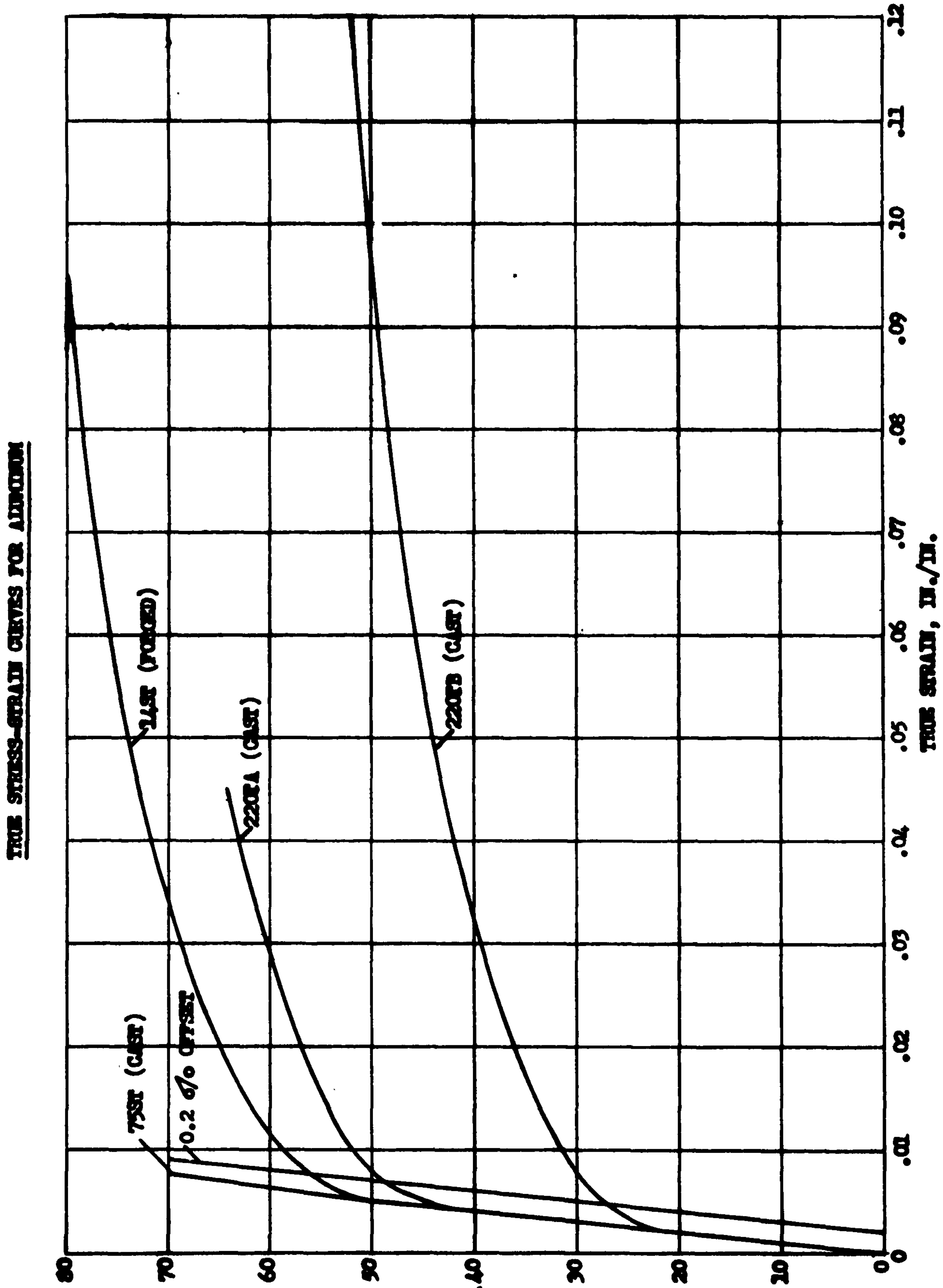
ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 17

CHASE MAIN LANDING GEAR TRUNNION
STRESS DISTRIBUTION IN CASTING--LOAD C



"CASTING POTENTIALS PROJECT"

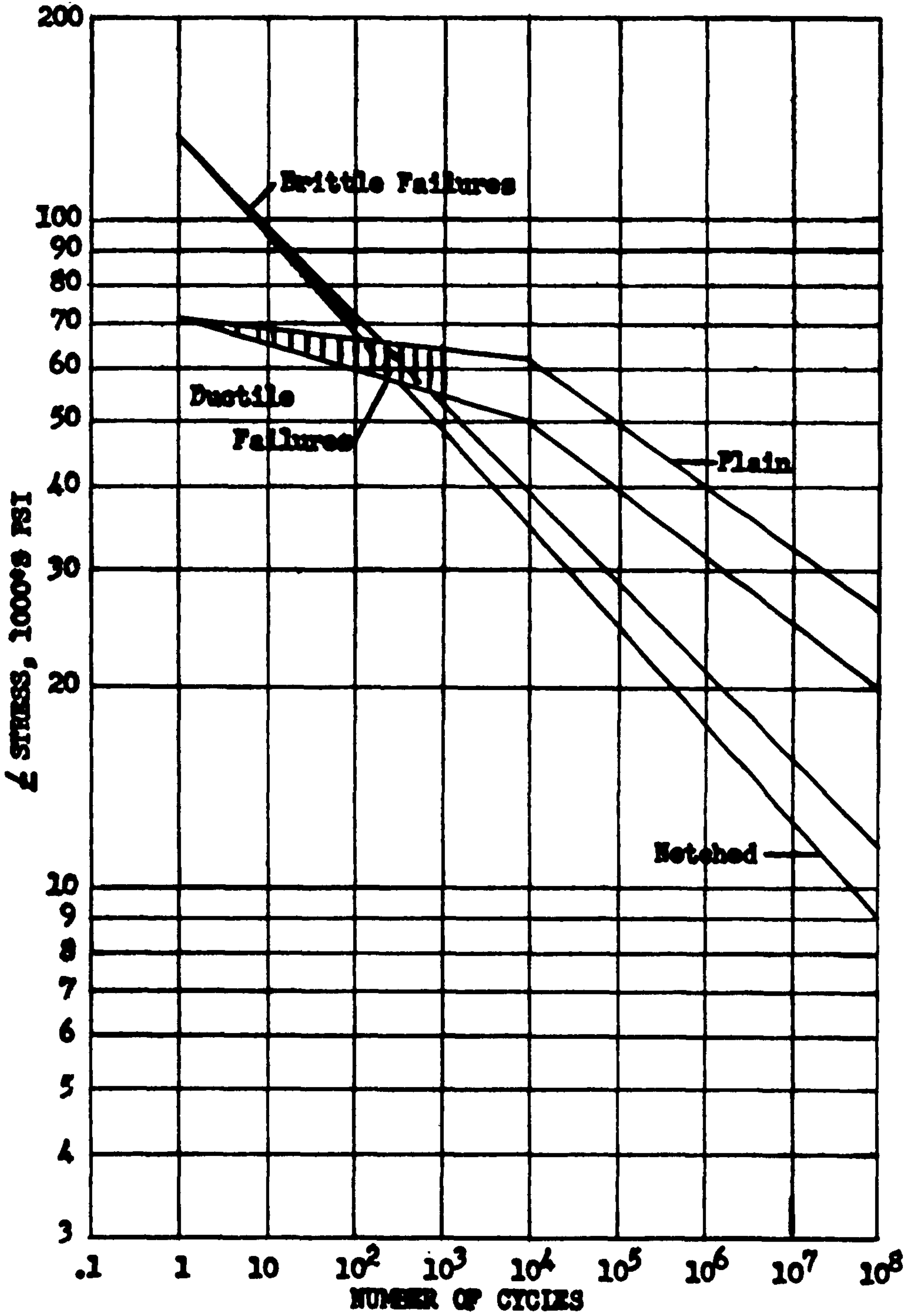
ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF FIG. 18



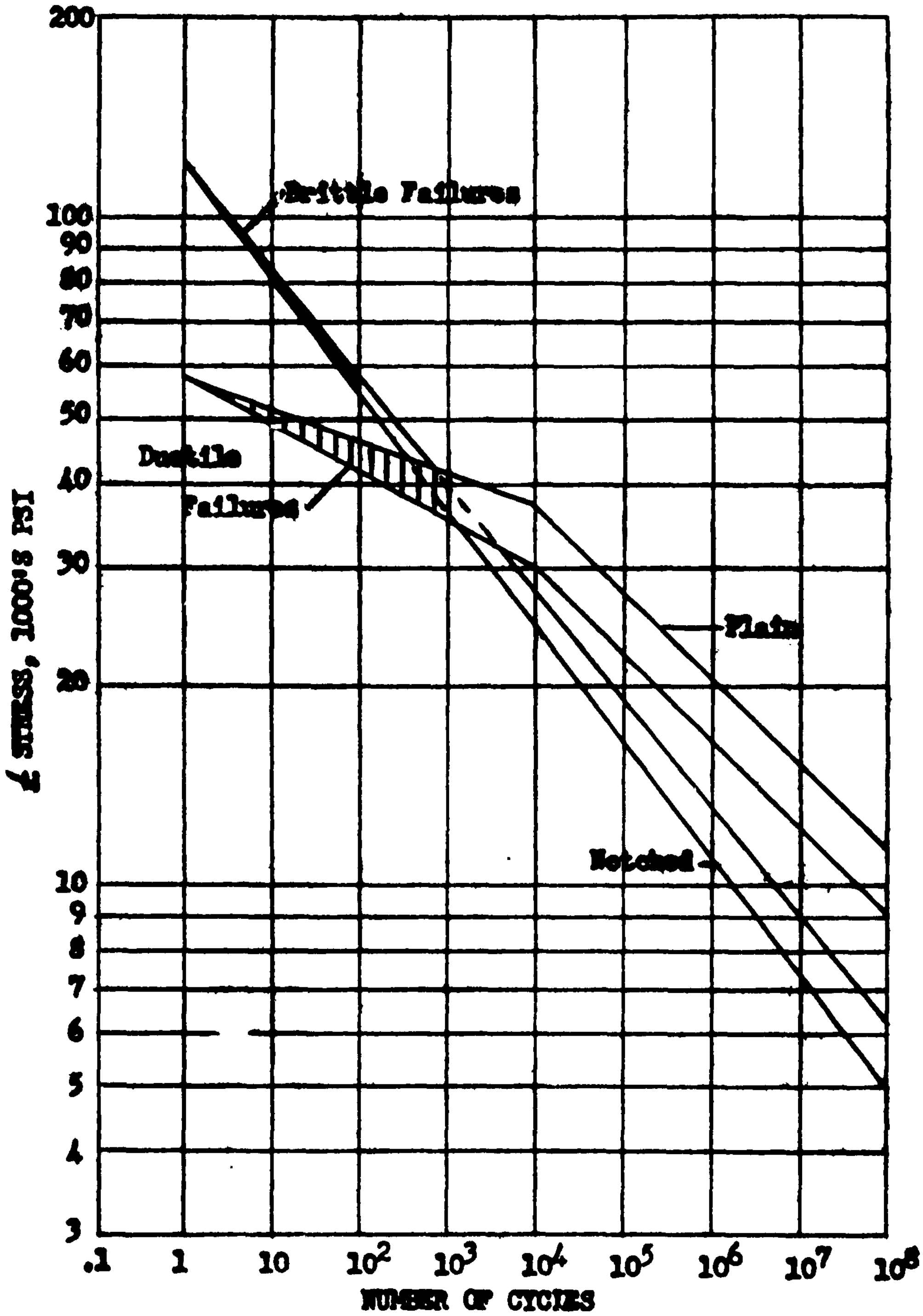
"CASTING POTENTIALS PROJECT"

ALLOY ENGINEERING & CASTING COMPANY, CHAMPAIGN, ILLINOIS--CONTRACTOR, AMC-USAF

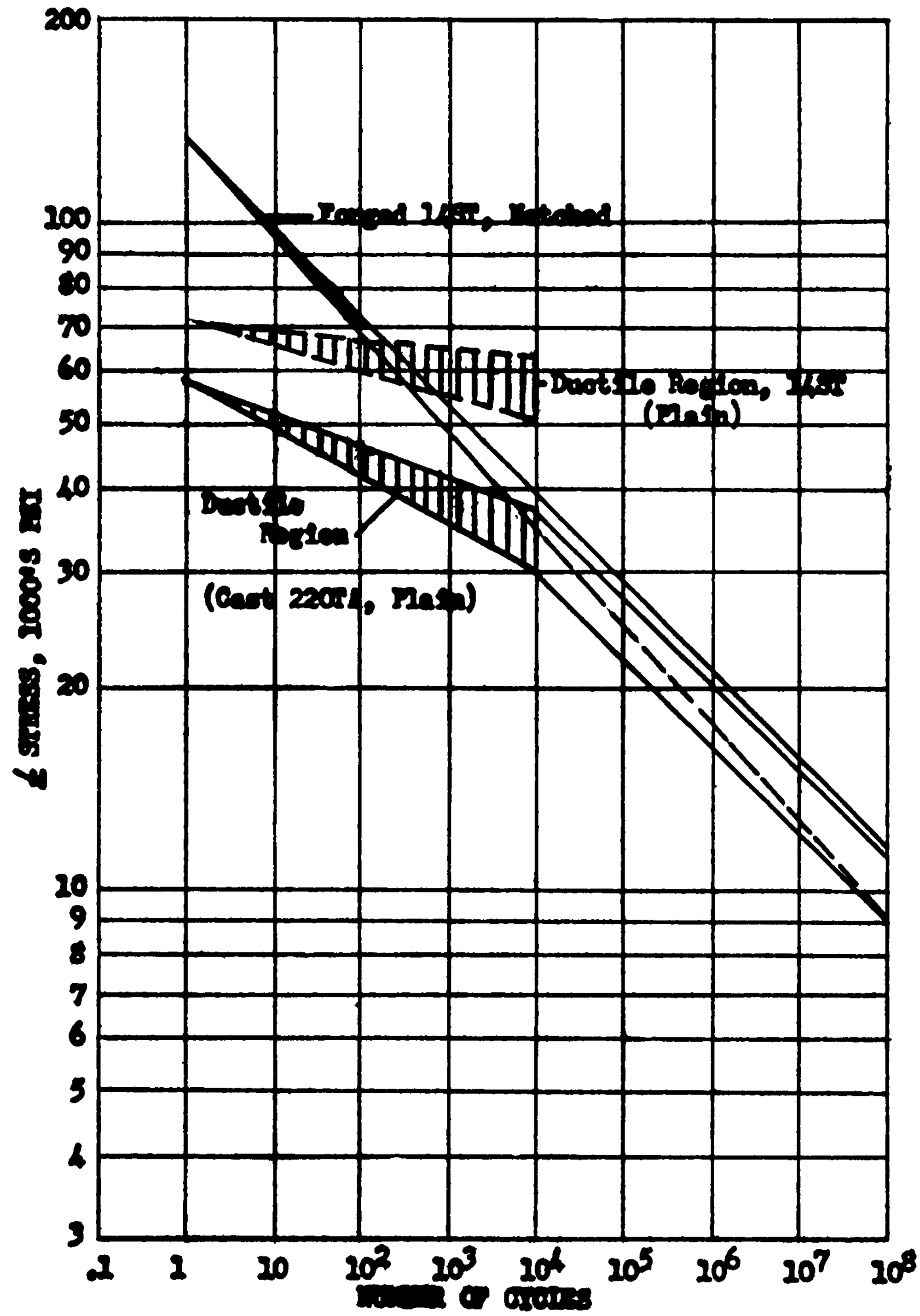
S-N CURVE FOR 14ST FORGED AL.
(Direct Stress)



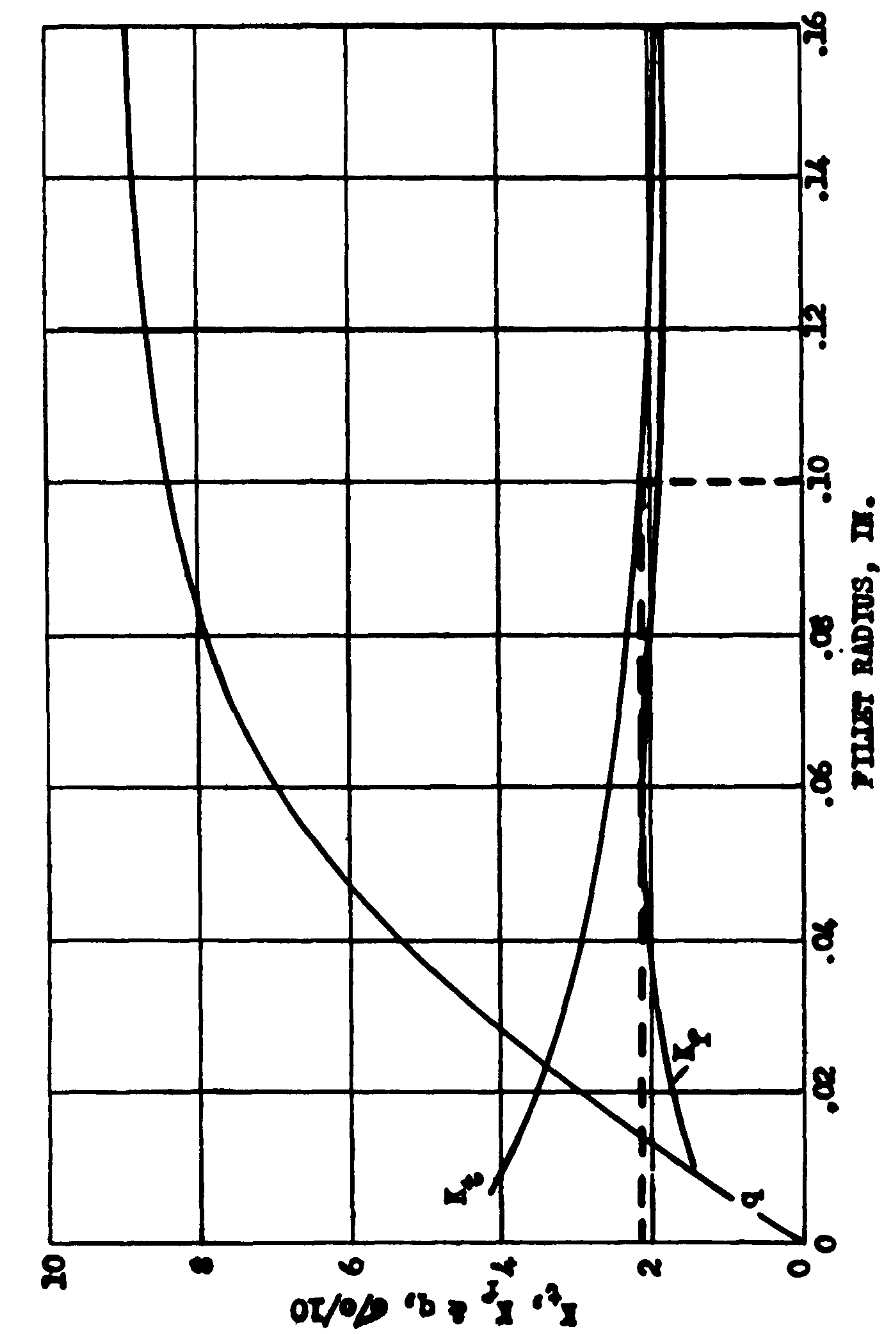
S-N CURVE FOR 220-TA CAST ALUMINUM
(Direct Stress)



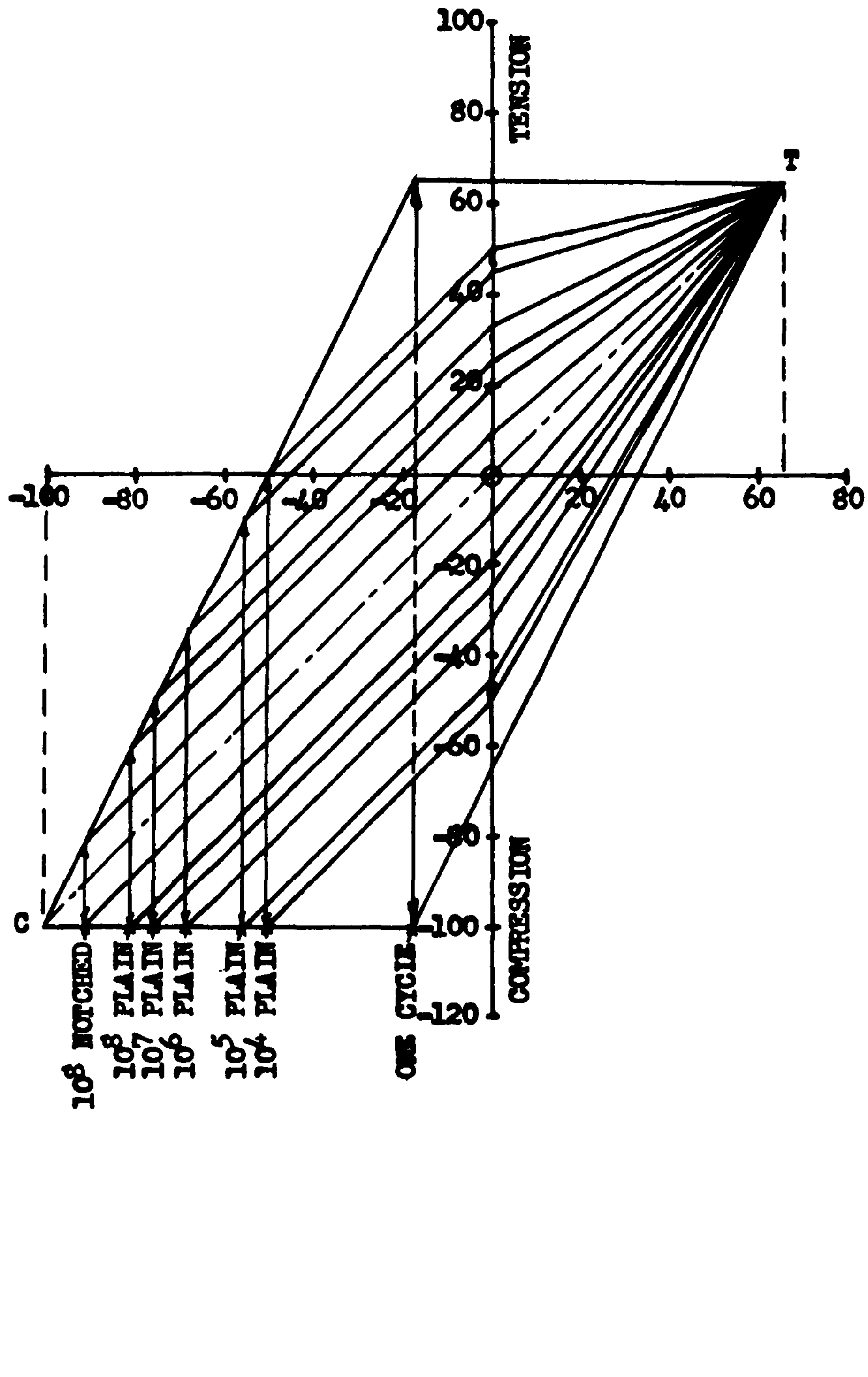
COMPARISON OF S-N CURVES FOR CAST & FORGED ALUMINUM



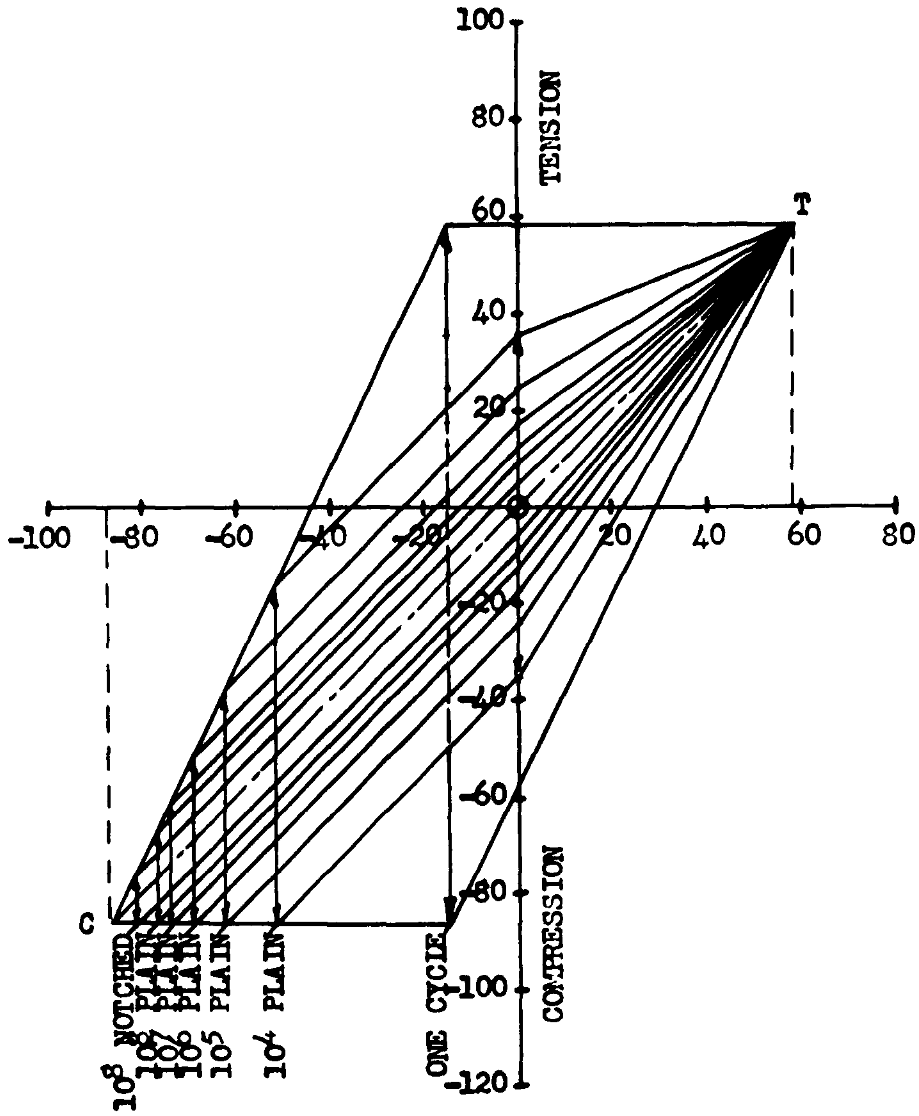
COMPARISON OF THEORETICAL & EXPERIMENTAL NOTCH FACTORS
(14ST FORGED ALUMINUM)



FAILURE DIAGRAM, 14ST FORGED ALUMINUM



FAILURE DIAGRAM, 220TA CAST ALUMINUM



SECTION IV - DOUGLAS C-124A NOSE LANDING GEAR TRUNNION

Douglas Aircraft Company, Inc., Long Beach, Cal., Part No. 8897A-14 A-1.

REPORT on Design Development and Stress Evaluation of Two Alternative Designs of Subject Airframe Component Designed as High-Integrity, High-Strength "Tublar-form" Alloy Steel Castings for Production by Advanced Process to Replace an "I" Section Aluminum Forging with Favorable Strength-Weight Comparison.

THIS SECTION INCLUDES:

A. DESIGN ALTERNATIVE A.

(Note: This design incorporates maximum probable employment of desirable minimum sectional gradient under imposed weight limitations.)

1. Casting Design-Process Consideration, and Design Development Procedure.
2. Perspective Sketches of Comparative Designs.
3. Drawing Douglas Part No. 8897A-14 A-1.
4. Contractor's Drawing No. CP-529, Design Alternative A.
5. Stress Analysis by Douglas of Original "I" Section Design.
6. Stress Analysis by Contractor of Design Alternative A. (Employing Contractor's normal procedure.)

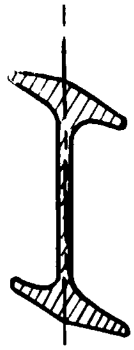
B. DESIGN ALTERNATIVE B.

Note 1: This design is a compromise in Contractor's casting design-process philosophy for initial producibility. Tentatively recommended for production. (See Conclusions.)

Note 2: Design developed by typical aircraft industry stress analysis method. No models employed.

1. Perspective Sketches of Comparative Designs.
2. Contractor's Drawing No. CP-566, Design Alternative B.
3. Stress Analysis by Contractor.

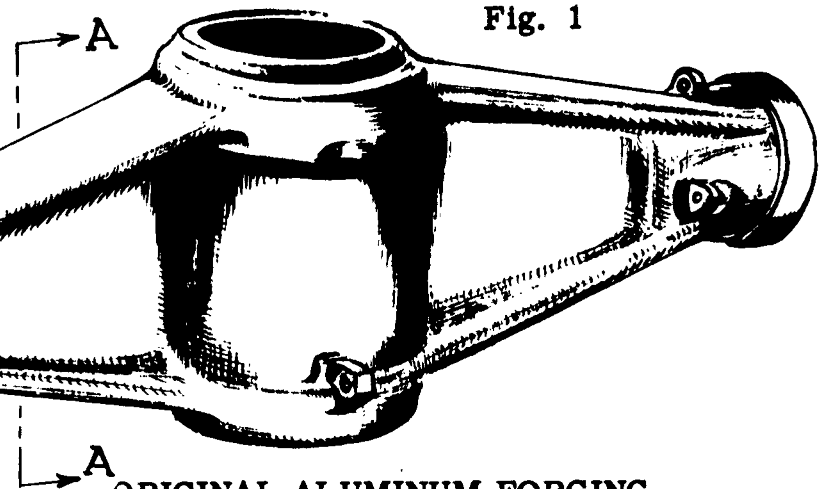
C. CONCLUSIONS: Relative to Producibility.



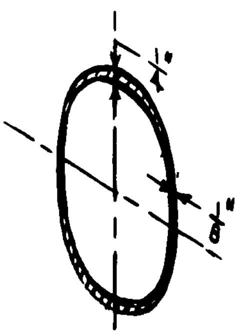
Section A-A

Fig. 1 shows Douglas Landing Gear Trunnion, an aluminum forging in production use.

Fig. 1

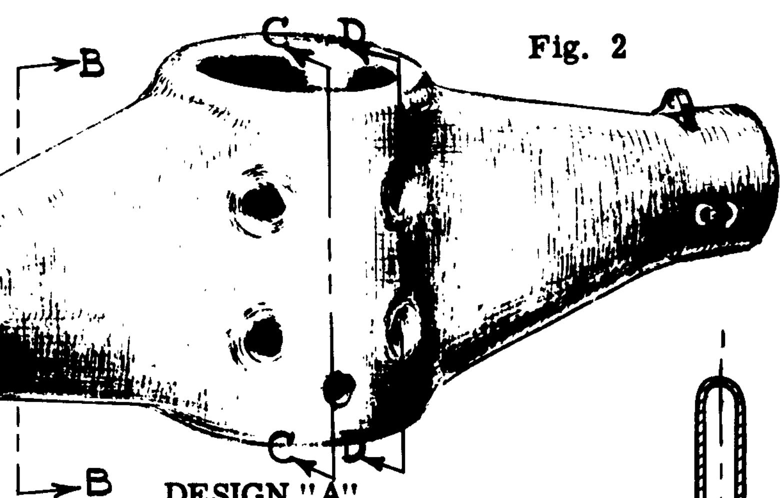


ORIGINAL ALUMINUM FORGING
DOUGLAS TRUNNION
Douglas Part No. 8897 A - 14 A1
Aircraft C-124A



Section B-B

Fig. 2



DESIGN "A"
Redesigned for Casting
DWG. No. CP-529

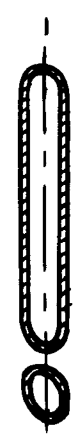


Fig. 2 shows Contractor's Design Alternate A, a redesign for production as a high integrity heat treated alloy steel casting. Casting design is based on 170,000 psi ultimate, considered a conservative figure. Weights of the forged and cast parts are approximately equal. Aluminum end bushings are employed in both designs. Wall section in main body is 1/8" thick on sides tapering to 1/4" on top and bottom, as noted on Section B-B.

Section C-C

Section D-D

SECTION IV - DOUGLAS C-124A NOSE LANDING GEAR TRUNNION

A. DESIGN ALTERNATIVE A.

1. CASTING DESIGN-PROCESS CONSIDERATION, and DESIGN DEVELOPMENT PROCEDURE.

Design objective is to maintain most uniform possible surface-to-mass ratios to minimize thermal differentials in metal solidification and subsequent heat treatment. The solidification rate and uniformity largely control shrinkage, structure, residual stresses, load deformation and service expectancy.

The Douglas Trunnion forging is basically an "I" beam cross section intersecting a tube at 90 deg. to its axis, at the center, and intersecting tubes parallel to its axis at its ends.

Redesign of the trunnion from an aluminum forging to a steel casting began with a preliminary design conference between Design Engineers, Casting Engineers and Stress Consultant. The various types of beam cross sections were considered, such as the "I" beam, "box" beam and possible "Tublarform" sections.

The inherent disadvantages of the "I" beam section for casting, principally its gross irregularities in surface-to-mass ratio resulting in irregular metal solidification with varying structures and residual stresses, eliminated this form.

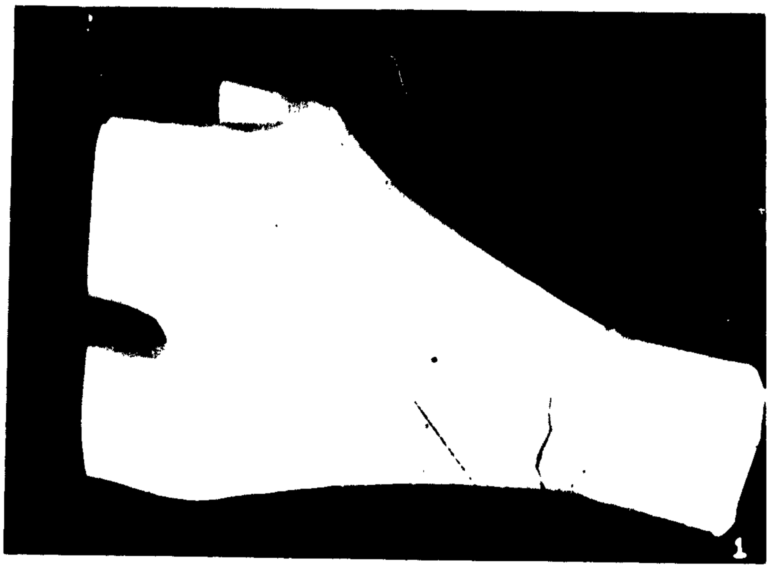
It was concluded that: (a) a "Tublarform" beam of oval cross section would provide best continuity of structure and best compromise in castability and thermal stress in heat treatment. (b) the "Tublarform" was structurally equal or superior to the "I" section.

Cardboard models portraying possible adaptions of the oval section were made for study purposes. One-half of the trunnion mocked up as a cardboard model is shown in Photos #1A and 1B. Model illustrates the oval beam section flowing over and around to form the cylindrical socket at 90 deg. to its axis at its center and cylindrical sockets parallel to its axis at its ends.

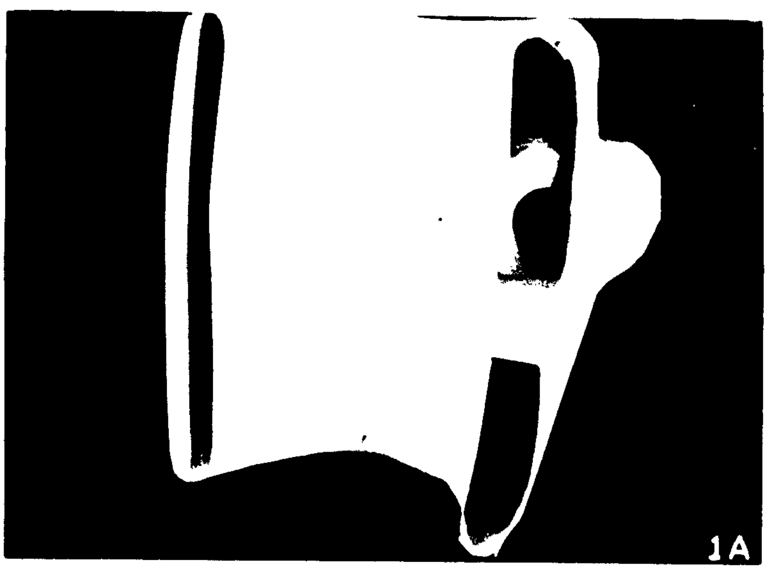
Following the cardboard models, ceramic models (Photo #2) made in plaster molds, were produced for general study purposes.

Further study of the oval beam design indicated that a better overall design would result from extending as far as possible toward the ends, and casting the axle pin as an integral part of the fitting (Photo #3). An investigation of the installation requirements in the airplane and of the maintenance requirements showed that the axle pins must be removable.

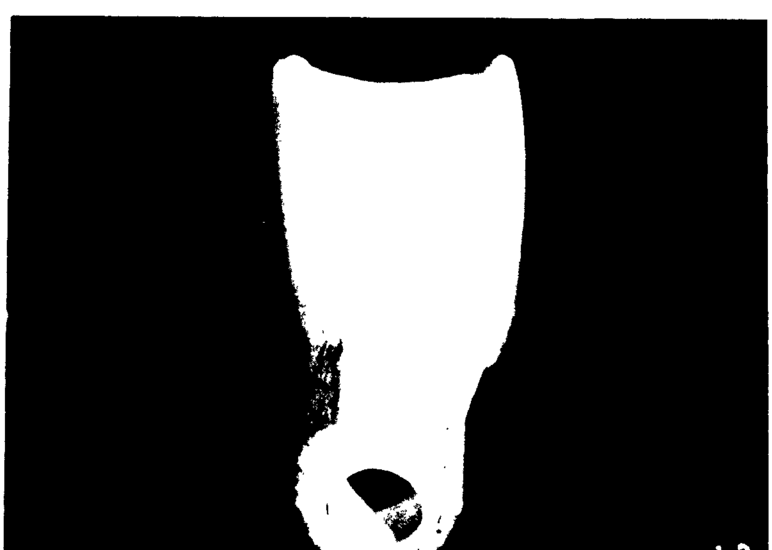
After further examination of the end socket design, it was found that acceptable weight-strength ratio could be obtained by an open-end tubular beam with an aluminum bushing pressed in to form the axle pin socket.



1



1A



1B

Photos #4 and 4A show the final design configuration with the walls of the oval beam tied thru to the center socket at four places on each side.

Basic mathematic checks were made as shown (see Stress Analysis) based on the assumption that 170, 000 psi tensile strength could be obtained in a heat treated cast steel part of this design. Stress data set "A" was calculated on the basis of a 1/4" minimum wall section in the casting. A weight check indicated that this would put the steel casting 25 lbs. over the weight of the aluminum forging. In order to reduce weight, consideration was given to 1/8" wall section wherever possible. Stress data set "C" was calculated on the basis of 1/8" side walls tapering to 1/4" in the oval beam and central socket. This involves compromise with Contractor's casting design-process philosophy that can only be resolved by experimental casting.

The design configuration shown in Photos #4 and 4A, with 1/8" thick side walls and 170, 000 psi tensile strength, is the final redesign of a steel casting to replace an aluminum forging on a strength-weight basis. 170, 000 psi ultimate is well below the properties which are attainable by advanced heat treating techniques from High-Integrity alloy steel castings. (Result of tests on sections cut from steel casting of Chase part: 200, 000 psi ultimate - 4. 5% to 6. 0% elongation.)

Illustrations, left page, show one-half of the trunnion mocked-up as a cardboard model. Model was employed in preliminary study of casting design-process study.

GEAR TRUNNION. A. DESIGN ALTERNATIVE A. and DESIGN DEVELOPMENT PROCEDURE.

Photo #1: Side view of one-half of the trunnion.

Photo #1A: Shows the "tublarform" double wall formed by the oval beam section flowing over and around to form the cylindrical "hub" socket at 90 deg. to its center axis.

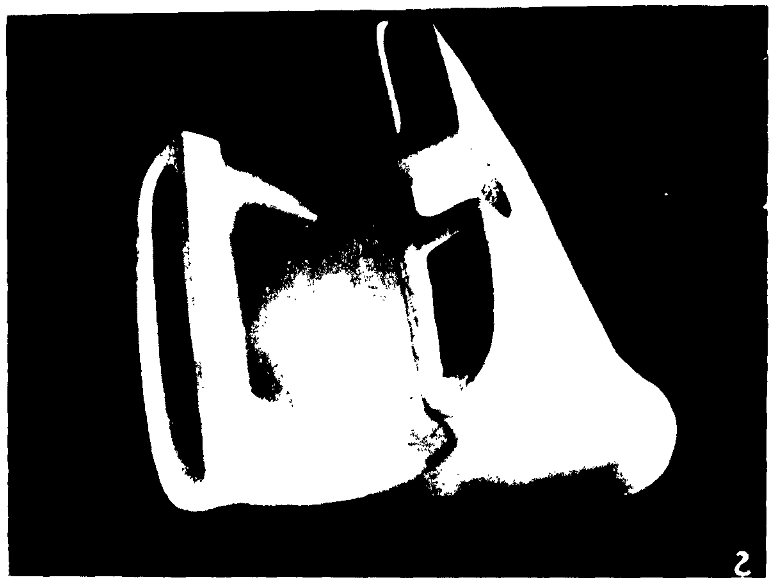
Photo #1B: End view of oval beam section terminating in axle socket with bushing inserted.

Photos, right page.

Photo #2: Shows trunnion with bushed end.

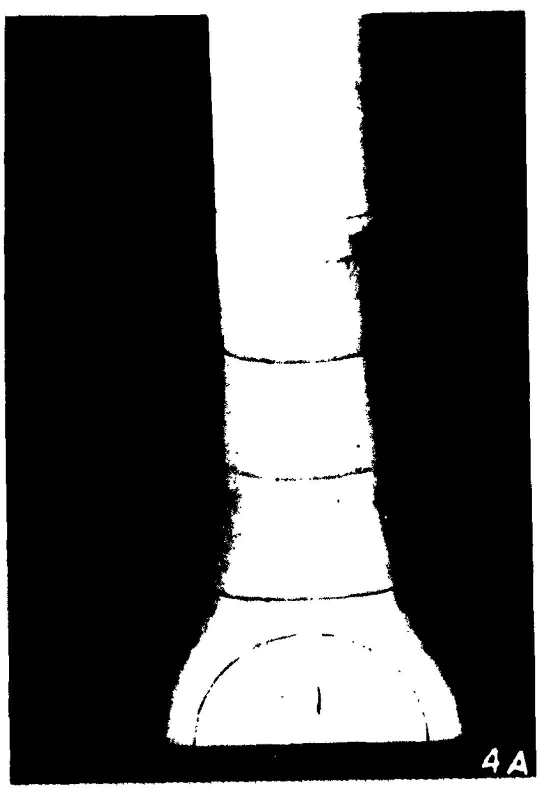
Photo #3: Shows trunnion form terminating in integral axle shaft.

Photos #4 and 4A: Show final design configurations.



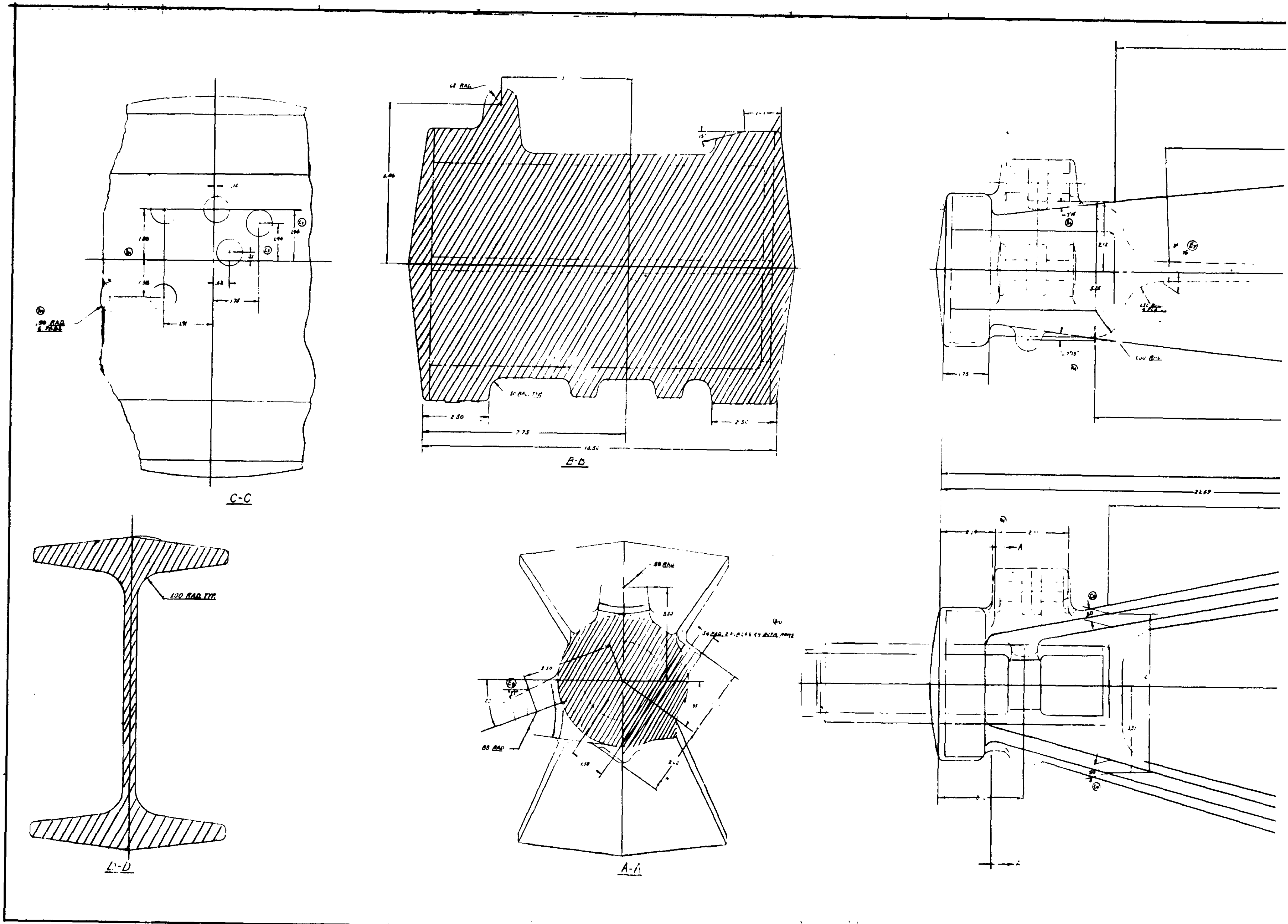
2

3

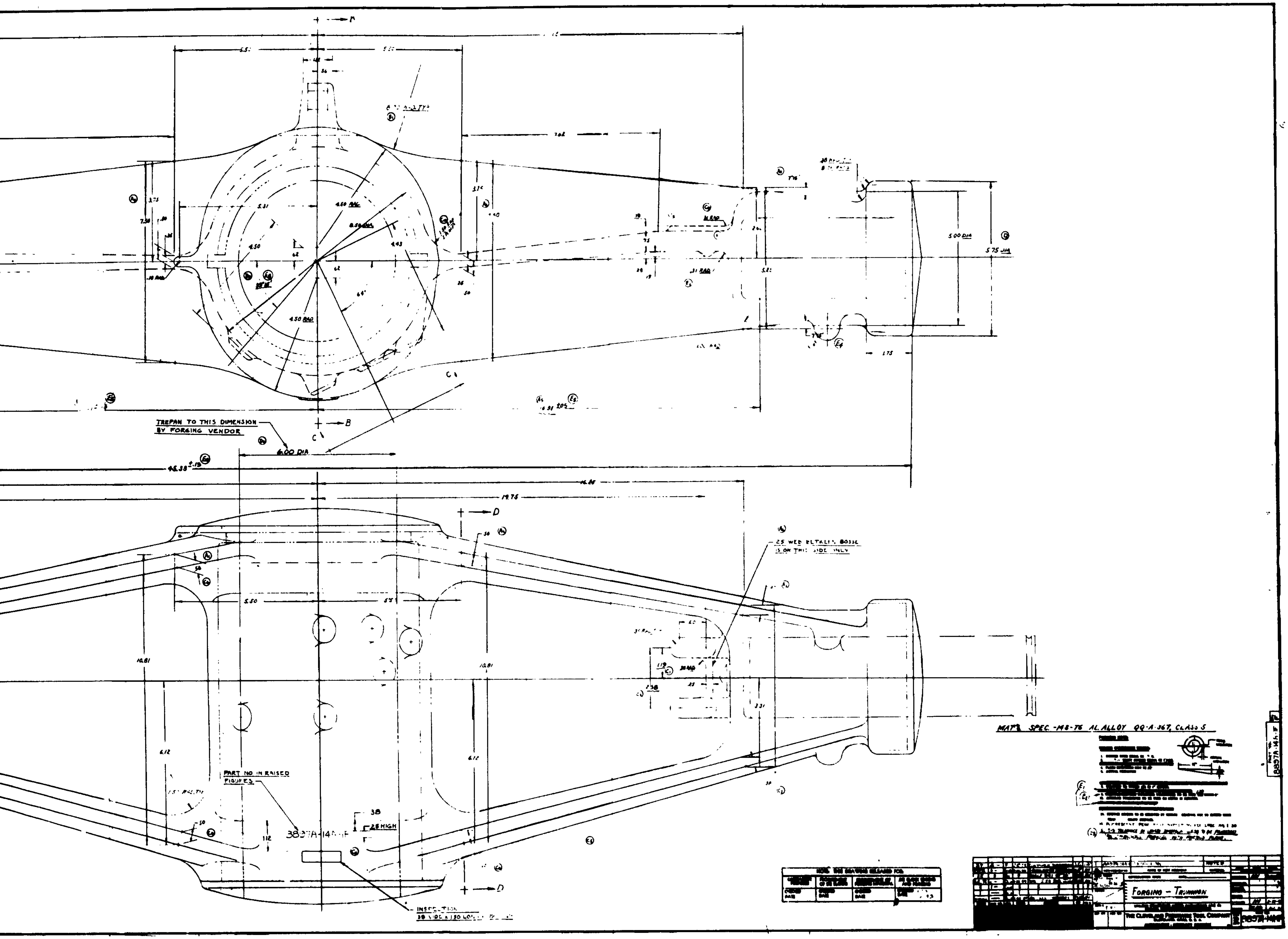


4A

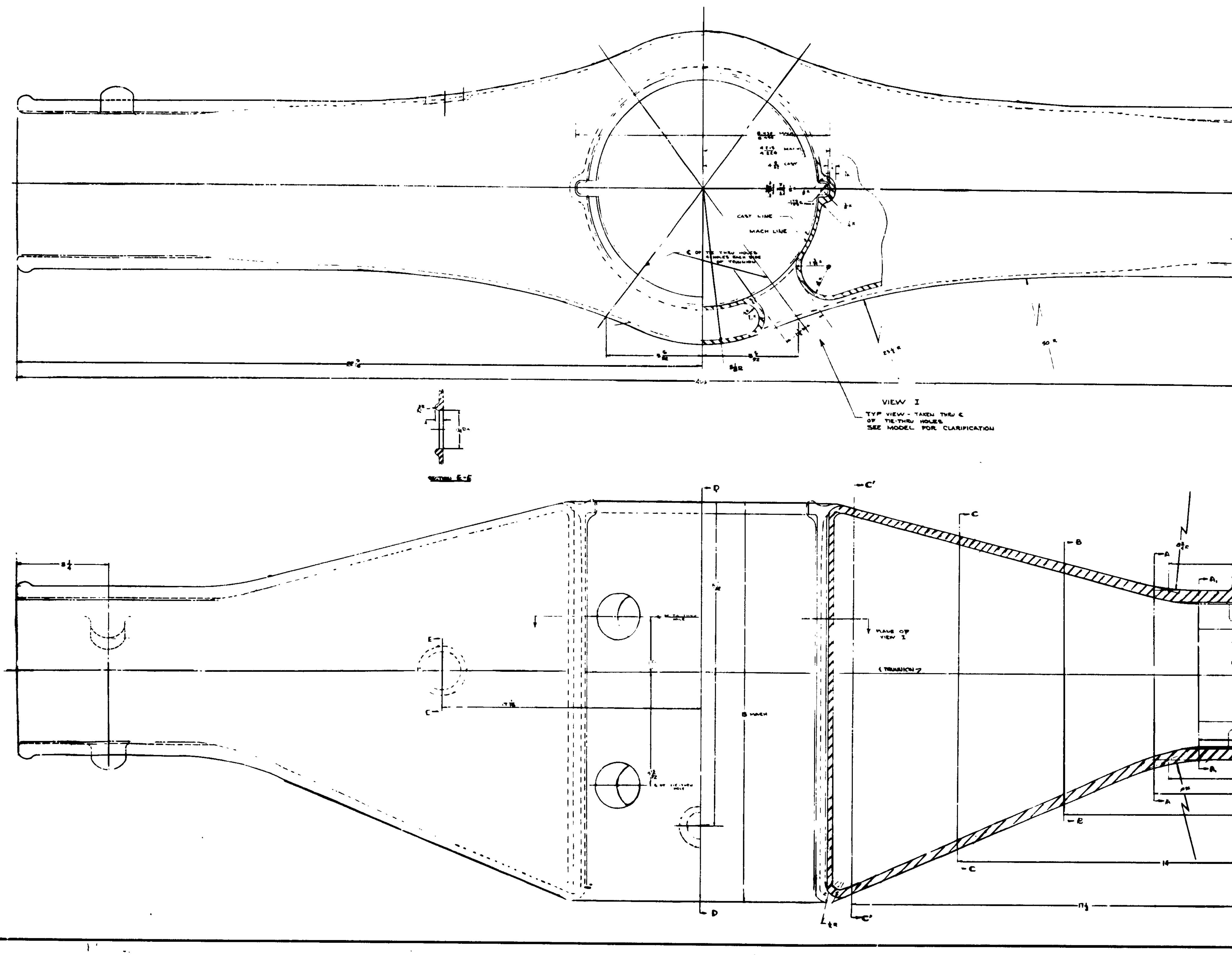
4



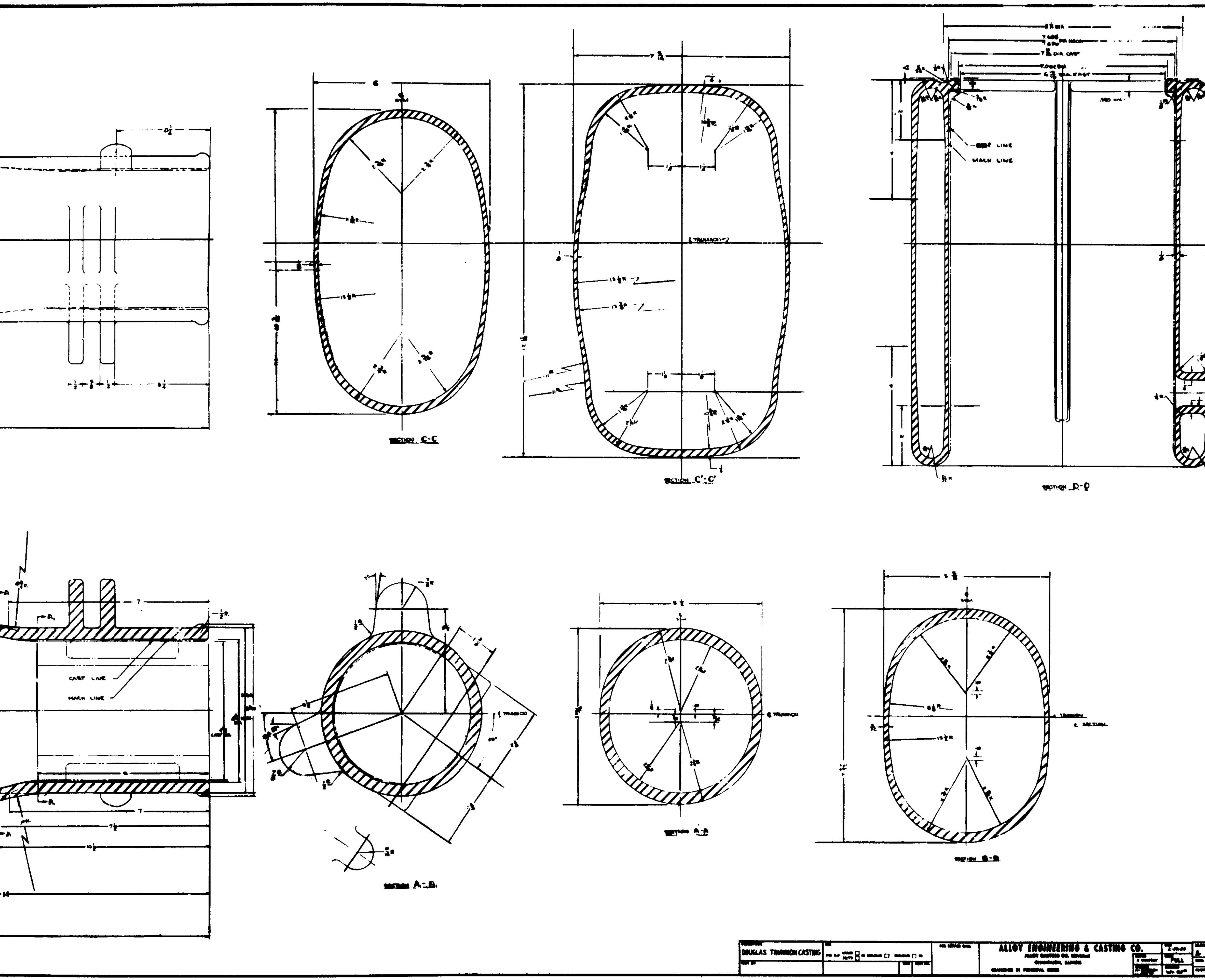
DOUGLAS AIRCRAFT COMPANY, INC., LONG BEACH,
PART NO. 3397
MATERIAL: ALUMIN



...ONG BEACH, C-124A, NOSE LANDING GEAR TRUNNION
... NO. 3S97A-14A-1F
...L: ALUMINUM FORGING



DESIGN ALTER
DOUGLAS C-124A NOSE LAN
REDESIGNED AS "TUBLARFORM" HIGH-STRENGTH STE
REDESIGNED FROM DOUGLAS PART NO. 8897A-1



ESIGN ALTERNATIVE A.
5A NOSE LANDING GEAR TRUNNION.
TRENGTH STEEL CASTING. A.E.C.CO. Dwg. NO. CP-529.
NO. 8897A-14-1F, ALUMINUM FORGING.

STRESS ANALYSIS

BY

DOUGLAS AIRCRAFT COMPANY, INC.

OF

NOSE GEAR TRUNNION

PART NO. 8897B-114

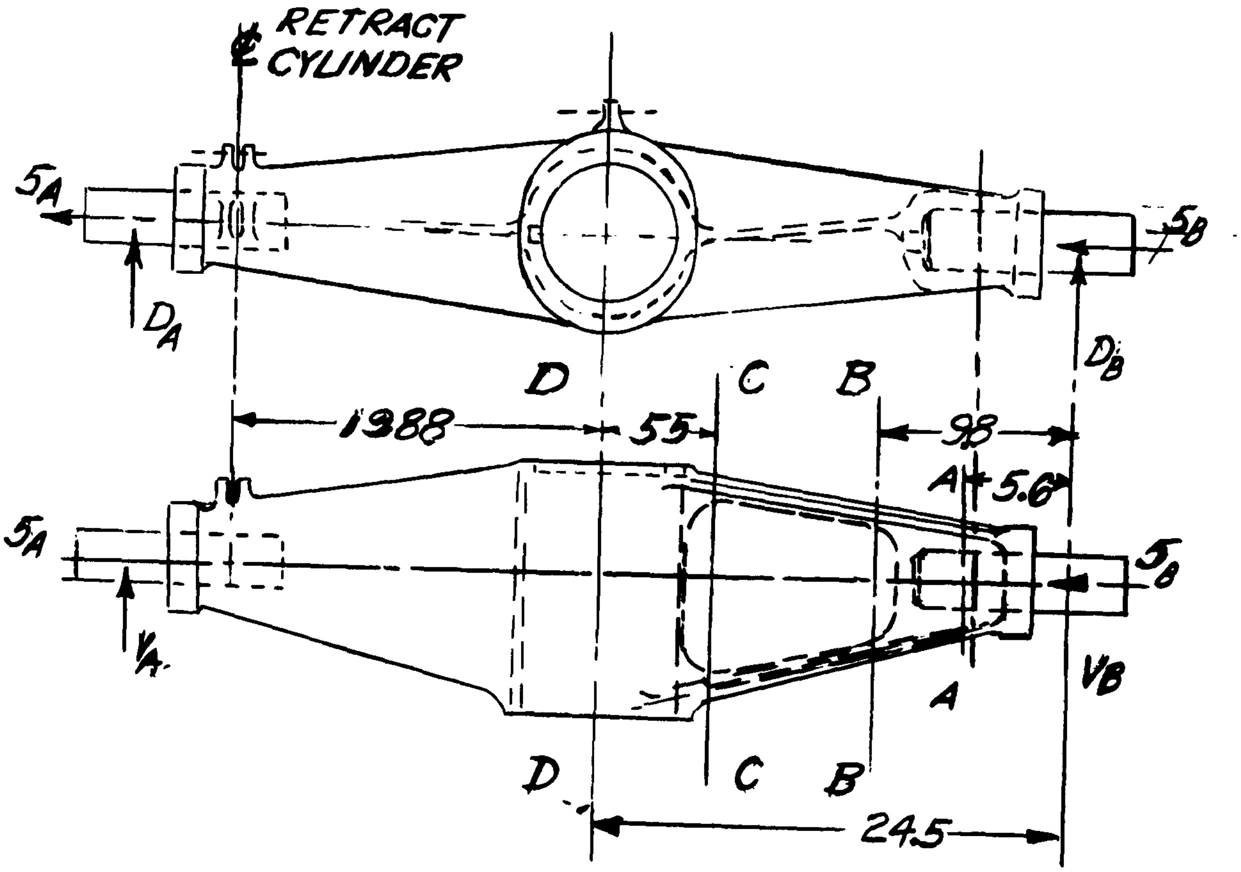
ENGINEERING STUDY

OF

FORGING

TRUNNION

8897A - TRUNNION ASSEMBLY



CRITICAL CONDITIONS AND LOADS*

	COND. 1a (2)	COND. 10a (2)	COND. 10b (2)
V_a (A_v) D_a (A_d)	21,970 41,090	61,950 2,245	79,255 1,285
V_b (B_v) D_b (B_d)	15,630 36,250	132,860 17,065	130,260 14,830
S $(S_a \text{ r } S_b)$	0	47,670	53,250

*CONSERVATIVE DIFFERENCES BETWEEN ABOVE LOADS & THE SUMMARY OF FUSELAGE REACTIONS (P.3.08) ARE CONSIDERED NEGLIGIBLE.

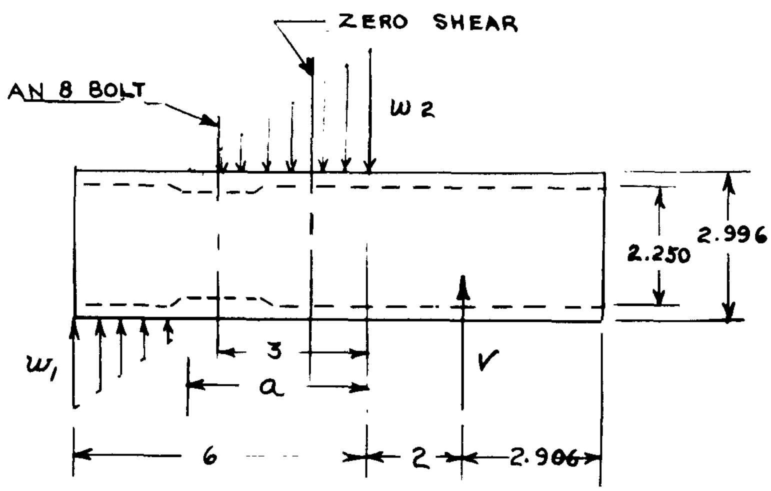
TRUNNION

8897A-14A-2
8897A-14A-3 TRUNNION END PINS

184000 H.T.
COND. $10a_{(2)}$ CRITICAL

MAX. SHEAR, $V = (132860)^2 + (17065)^2$ PG 8.01

$= 133900\#$



$$w_1 = \frac{133900}{(3)}\frac{(5)}{}\frac{(6)}{(6)^2} - \frac{133900}{(3)(6)}$$

$$= 37200 - 7400 = 29800 \text{ psi}$$

$$w_2 = 37200 + 7400 = 44,600 \text{ psi}$$

BEARING OF PIN ON 14 ST FORGED TRUNNION

$F_{br} = 9800$ M.S. $= \dfrac{9800}{2.0 \times 44600} - 1 = .10$

TO FIND A----

$$\frac{44600}{a} = \frac{29800}{6-a}$$

$$29800\,a - 267600 = 44600a$$

$$a = \frac{267600}{74400} = 3.6$$

ARM TO CENTROID OF TRAPEZOIDAL LOAD

MAX. MOMENT $= 133900\,(2.0 + 1.2 - .64)$
$= 343000$ in-lbs.

TRUNNION

SECTION PROPERTIES OF PIN

$OD = 2.996 \quad ID = 2.250$
$(OD)^2 = 8.976 \quad (ID)^2 = 5.063$
$(OD)^3 = 26.892 \quad (ID)^3 = 11.391$
$(OD)^4 = 80.569 \quad (ID)^4 = 25.629$

$t = .373$
$D/t = 8$

$b = .746$
$A = .7854\ (8.976 - 5.063) = 3.07$
$I = .0491\ (80.569 - 25.629) = 2.70$
$Q = .0833\ (26.892 - 11.391) = 1.29$

BENDING OF PIN

$$f_b = \frac{343000 \times 1.498}{2.70} = 190{,}000 \text{ psi}$$

$$F_b = 270000 \qquad M.S. = \frac{270000}{190000} - 1 = \underline{\underline{.42}}$$

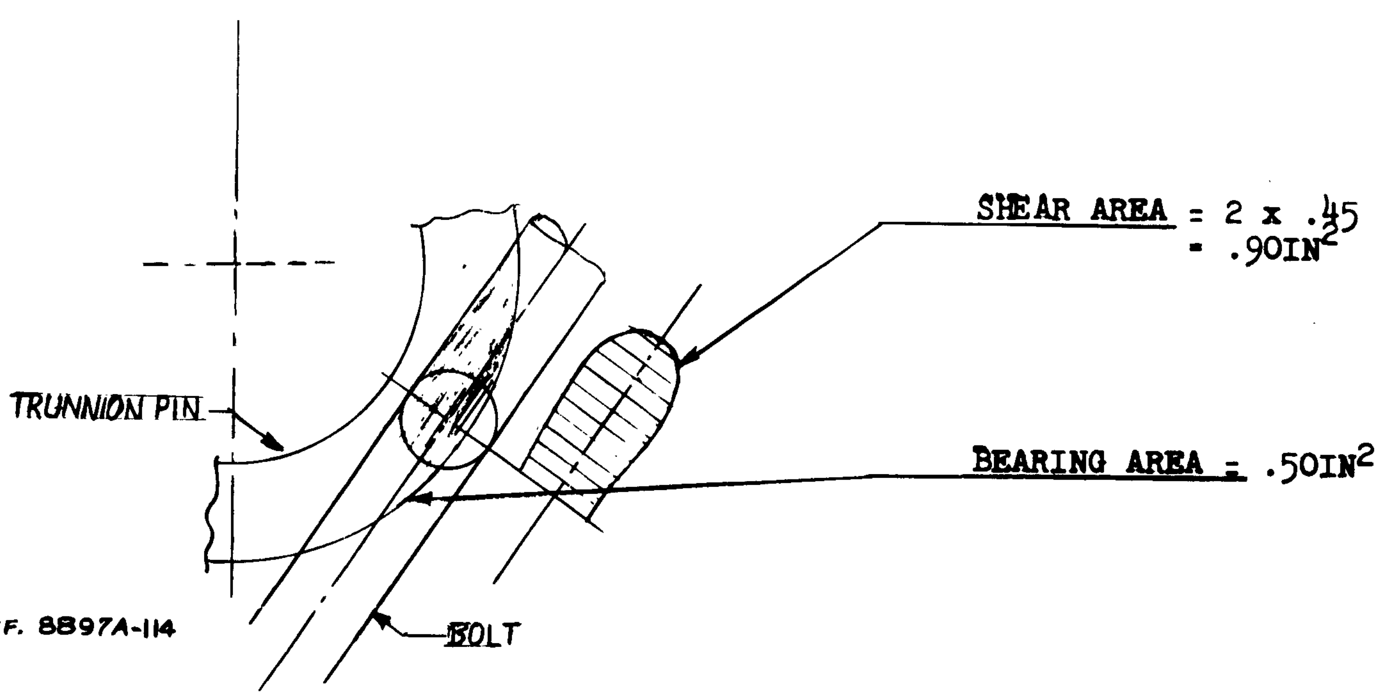
SHEAR OF PIN

$$f_s = \frac{133900 \times 1.29}{2.70 \times .746} = 85700 \text{psi}$$

$$F_s = 105000 \qquad M.S. = \frac{105000}{85700} - 1 = \underline{\underline{.22}}$$

AN 8 BOLT (THRU TRUNNION AND PINS)

SHEAR AREA BY PLANIMETER



REF. 8897A-114

TRUNNION

AN 8 BOLT CONT'D.

COND 10b CRITICAL
SIDE LOAD = 53250#
LOAD/BOLT = (.67)*(53250) = 35600 #

$f_s = \frac{35600}{.9} = 39600$ psi

$F_s = 75,000$ M.S. $= \frac{75000}{1.15 \times 39600} - 1 = .65$

$f_{br} = \frac{35600}{.5} = 71200$ psi

$F_{br} = 175000$ M.S. $= \frac{175000}{2.0 \times 71200} - 1 = 23$

8897A-14A-1 TRUNNION

14ST FORGING 6500 H.T.
MAX. SHEAR, SECT. A-A (PG.8.01)
COND. 10a(2) CRITICAL

$V = \frac{44600 \times 3 \times 3.6}{2} = .241000\#$ PG 8.02

ASSUME SECTION CIRCULAR WITH O.D. = 5.0
AND I.D. = 3.0 REF. 8897A-14A-1F

$I = .7854(2.5^{-4} - 1.5^{-4}) = 26.7$
AREA, HALF SECTION $= 1.5708\,(2.5^{-2} - 1.5^{-2}) = 6.29$

$\bar{y}$, HALF SECTION $= .4244 \frac{(2.5)^3 - (1.5)^3}{(2.5)^2 - (1.5)^2} = 1.30$

$Q = 6.29 \times 1.30 = 8.17$

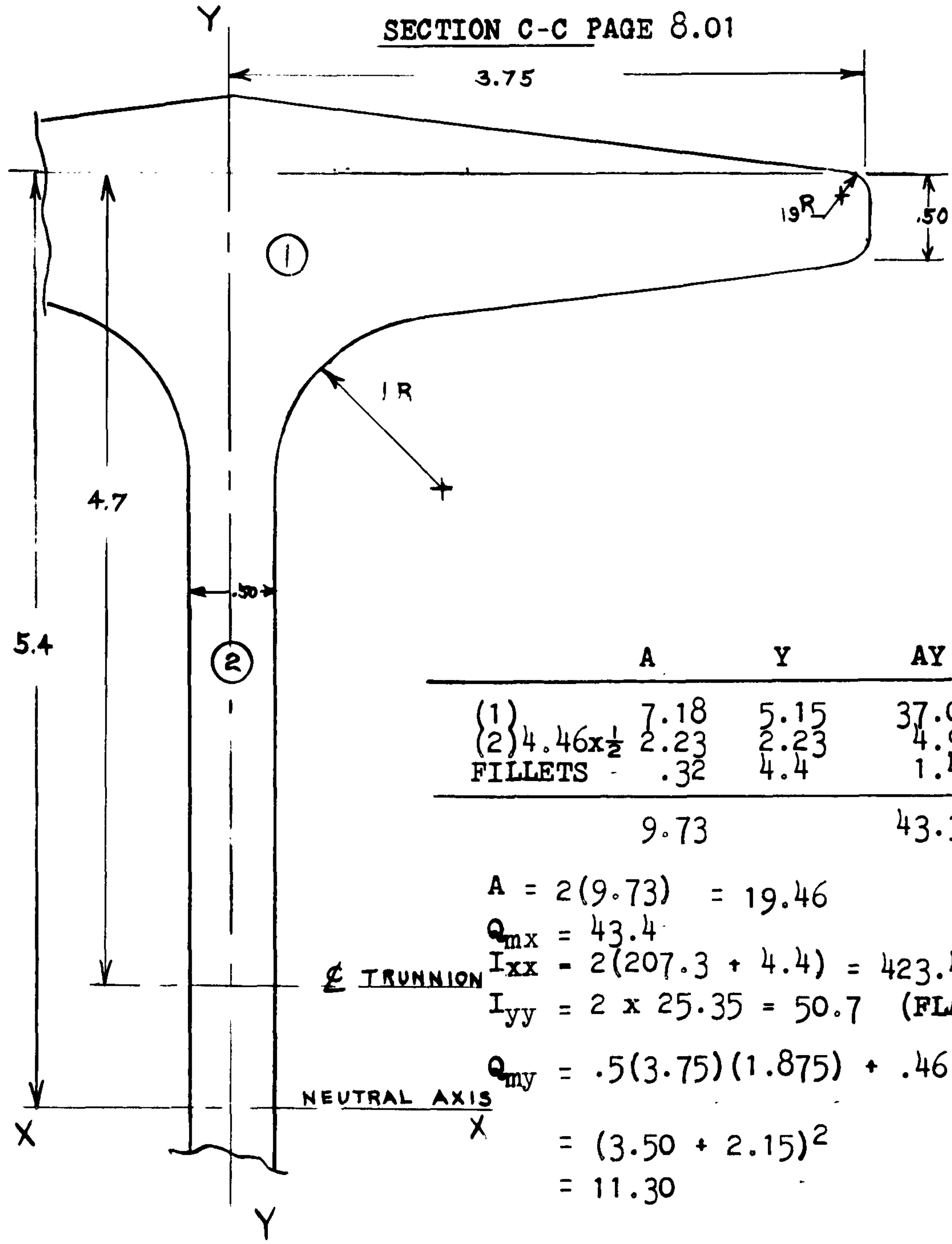
$f_s = \frac{241000 \times 8.17}{26.7 \times 2.0} = 36900$ psi

$F_s = 39000$ M.S. $= \frac{39000}{36900} - 1 = .055$

* ASSUME 2/3LOAD TO ONE SIDE.

TRUNNION

SECTION C-C PAGE 8.01



	A	Y	AY	AY^2	I_o
(1)	7.18	5.15	37.0	190.0	.7
(2) 4.46x½	2.23	2.23	4.97	11.1	3.7
FILLETS	.32	4.4	1.41	6.2	-
	9.73		43.38	207.3	4.4

$A = 2(9.73) = 19.46$

$Q_{mx} = 43.4$

$I_{xx} = 2(207.3 + 4.4) = 423.4$

$I_{yy} = 2 \times 25.35 = 50.7$ (FLANGES ONLY)

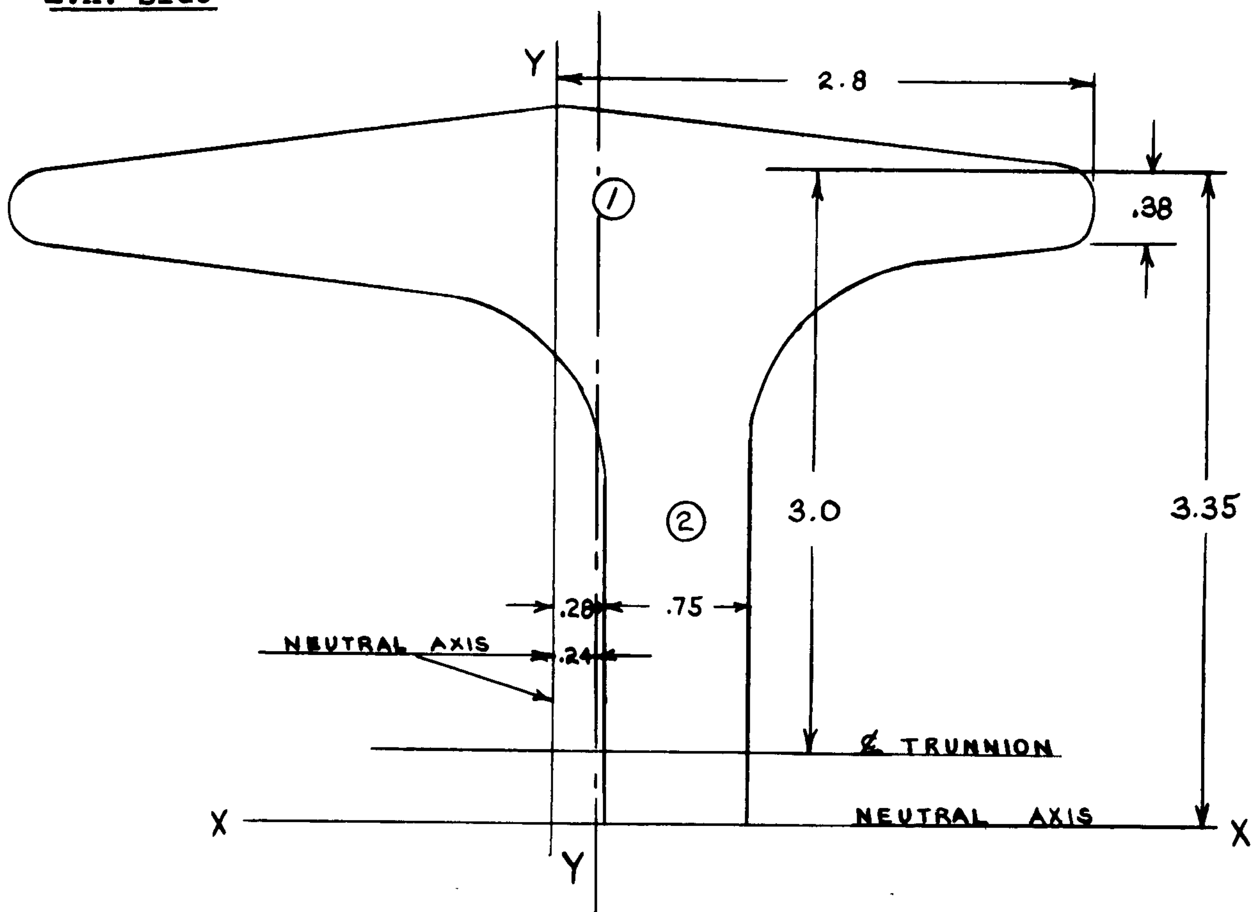
$Q_{my} = .5(3.75)(1.875) + .46(3.75)(1.25)^2$

$= (3.50 + 2.15)^2$

$= 11.30$

TRUNNION

SECTION B-B PG. 8.01
L.H. Side



	A	Y	Ay	AY²	I_o
(1)	4.0	3.16	12.64	39.9	.22
(2) 2.7x.75	2.02	1.35	2.73	3.7	1.23
FILLETS	.32	2.55	.82	2.1	---
	6.34		16.2	45.7	1.45

$A = 2(6.34) = 12.7$

$Q_{mx} = 16.2$

$I_{xx} = 2(45.7 + 1.45) = 94.3$

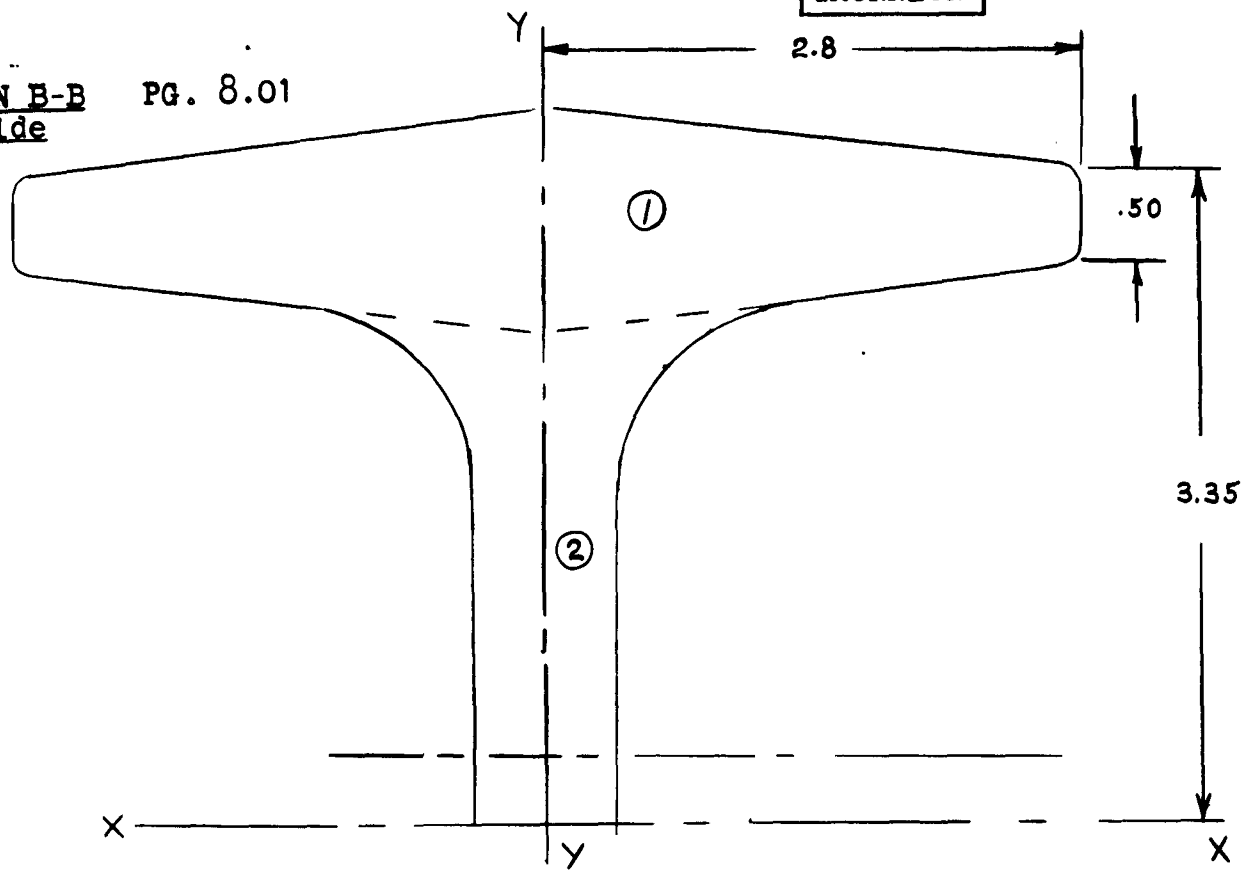
(1)	4.0				7.7
(2)	2.02	.655	1.32	.87	.10
FILLET	.16	.09	.01	---	----
FILLET	.16	1.22	.20	.25	----
	6.34	.24	1.53	1.12	7.8

$I_{yy} = 2\left[7.8 + 1.12 - 6.34(.24)^2\right] = 17.1$

$Q_{my} = \left[.38(2.8)(1.4 + .24) + .34(2.8)(2.8/3 + .24) + .24(1.04)(.12)\right]2$
$= 5.74$

TRUNNION

SECTION B-B PG. 8.01
R.H. Side



	A	Y	AY	AY^2	I_o
(1)	4.7	3.10	14.57	45.2	.3
(2) 2.55x.75	1.91	1.27	2.43	3.1	1.0
FILLETS	.32	2.43	.78	1.9	----
	6.93		17.78	50.2	1.3

$A = 2(6.93) = 13.8$

$Q_{mx} = 17.8$

$I_{xx} = 2(50.2 + 1.3) = 103.0$

$I_{yy} = 2 \times 9.7 = 19.4$ (FLANGES ONLY)

$$Q_{my} = \left[.5(2.8)(1.4) + .34(2.8)(2.8/3)\right]^2$$
$$= (1.96 + .89)^2$$
$$= 5.70$$

ANAL. NOSE GEAR
PREP. HAMMIL
DATE 5-13-49

DOUGLAS AIRCRAFT COMPANY, INC.
6B PLANT

MODEL C-124A
Rept. No. 10351

MARGINS OF SAFETY BASED ON COZZONE METHOD.
REF. JOURNAL OF AERO. SCIENCES

FORGING SECTION ANALYSIS

TRUNNION

		(1)	(2)	(3)	(4)	(5)	
		SECTION L.H.SIDE	B-B CRITICAL	SECTION	C-C	SECT.B-B r.h.side	
	COND.	1a2	10a2	1a2	10a2	RETRACT	
(1)	Vb or Va Pg. 8.01	21970	132860	21970	132860		
(2)	Db or Da Pg. 8.01	41090	17065	41090	17065		
(3)	Sb or Sa Pg. (2/35)	0	31800	0	31800	SEE PG. 8.19	
(4)	l Pg. 8.01	9.8	9.8	19.0	19.0		
(5)	Mx (1)x(4)	215000	130000	417000	252000		
(6)	My (2)x(4)	402500	167000	780000	324000		
(7)	Area Pg. 8.05, 8.06, 8.07	12.7	Same as (1)	19.5	Same as (3)		
(8)	Ix Pg. 8.05, 8.06, 8.07	94.3		423.4		103.0	
(9)	Iy Pg. 8.05, 8.06, 8.07	17.1		50.7		19.4	
(10)	Cx Pg. 8.05, 8.06, 8.07	3.69		5.86		3.69	
(11)	Cy Pg. 8.05, 8.06, 8.07	3.04		3.75		2.8	
(12)	(I/c)x (8)/(10)	25.55		72.2		27.9	
(13)	(I/c)y (9)/(11)	5.62		13.5		6.92	
(14)	Qmx Pg. 8.05, 8.06, 8.07	16.2		43.4		17.8	
(15)	Qmy Pg. 8.05, 8.06	5.74		11.3		5.70	
(16)	kx 2x(14)/(12)	1.27		1.20		1.27	
(17)	ky 2x(15)/(13)	2.00		1.67		1.65	
(18)	Fbux *	81000		77000		81000	
(19)	Fbyx **	55700		54200		--	
(20)	Fbuy *	125,000		105000		63,800	
(21)	Fbyy **	71,200		64200		--	
(22)	Mx (12)x15(19) or (18)	2,060000		5560000		2260000	
(23)	My (13)x1.5(21) or (20)	600,000	Same as (1)	1300000	Same as (3)	662,000	
(24)	Fa 65000 (7)	----	825000	---	1268000		
(25)	Rx (5)/(22)	.104	.631	.075	.453		
(26)	Ry (6)/(23)	.671	.279	.600	.249	SEE PG. 8.19	
(27)	Ra (3)/(24)	0	.039	0	.025		
(28)	M.S. $\frac{1}{(25)+(26)+(27)}-1$	.29	.054	.48	.37		
*	Fbu = 65000 [1 + .920(k-1)]						
**	Fby = 50000 [1 + .423(k-1)]						

TRUNNION FORGING - CONT'D.

MAX. SHEAR, SECT. B-B R.H. SIDE, PG8.07

$$f_s = \frac{132860 \times 17.8}{103.0 \times .75} = 30600 \text{ psi}$$

$$M.S. = \frac{39000}{30600} - 1 = \underline{\underline{.27}}$$

NOTE: THE TORSION ON THE L. H. SIDE DUE TO ECCENTRICITY OF THE WEB MAY BE CARRIED BY DIFFERENTIAL BENDING OF THE FLANGES. SEE ANALYSIS FOR TORQUE RESULTING FROM RETRACTING STRUT.

MAX. SHEAR, SECT. C-C

$$f_s = \frac{132860 \times 43.4}{423.4 \times .50} = 27{,}200 \text{ psi}$$

$$M.S. = \frac{39000}{27200} - 1 = \underline{\underline{.43}}$$

TRUNNION

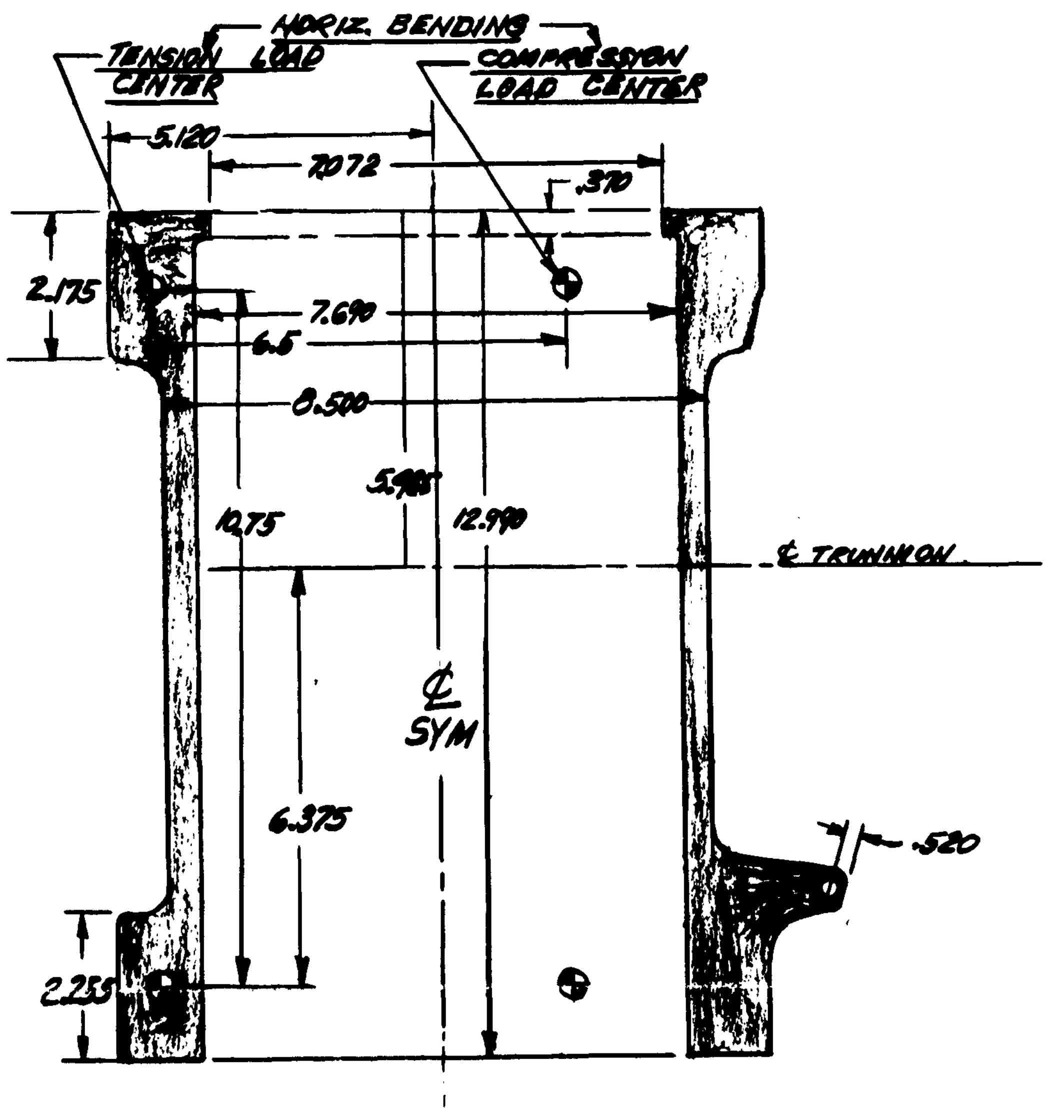
SECTION D-D AT ℄

DIMENSIONS SHOWN ARE WITH TOLERANCES TO GIVE MINIMUM UPPER FORWARD FLANGE AREA.

$$A = (5.120-3.845)(2.175)$$
$$= 2.77 \text{ IN}^2$$

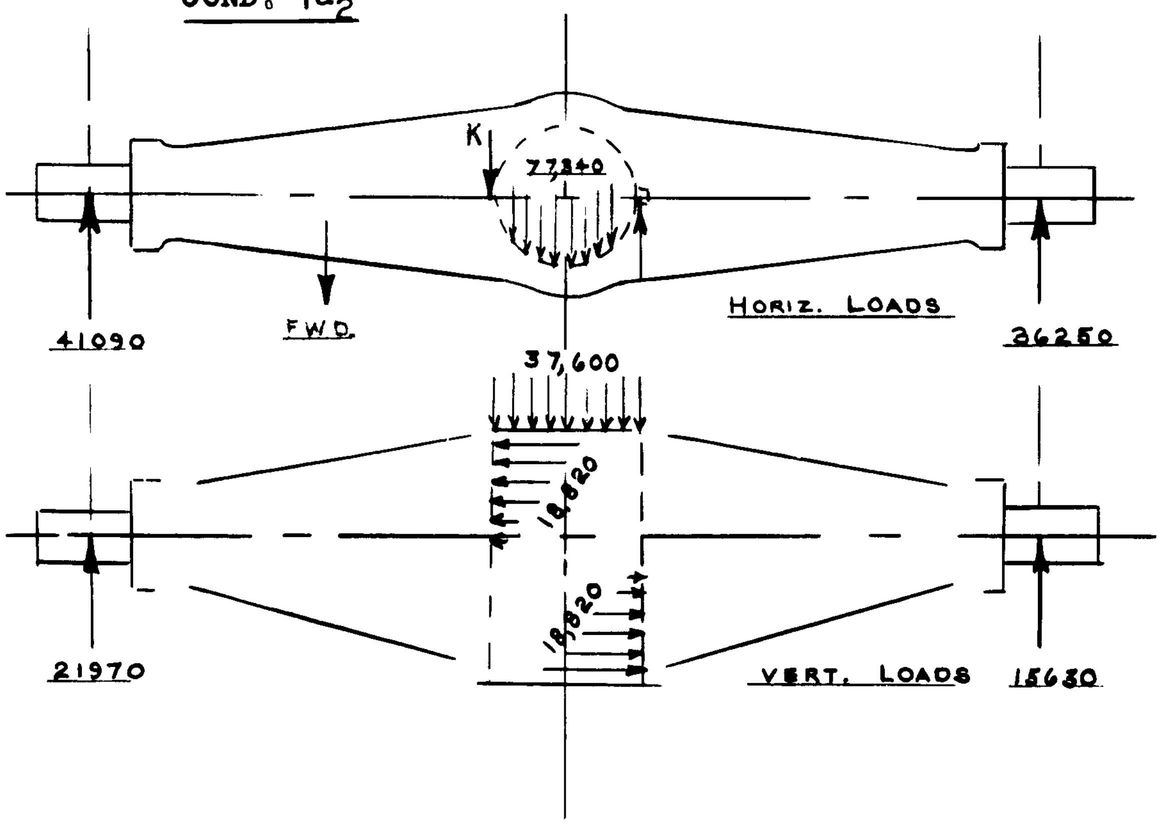
TOTAL CROSS SECTION

$$\text{AREA} = (12.99-4.43)(8.50-7.69) + 4(2.77)$$
$$= 18.0 \text{ IN}^2$$



TRUNNION

SECTION D-D ANALYSIS
COND. $1a_2$



KEY LOAD, K = $\frac{(41,090 - 36,250)24.5}{7.688}$ = 15,430#

THE BENDING IN THE HORIZONTAL PLANE IS CARRIED BY TENSION IN THE FORWARD FLANGES AND COMPRESSION ON THE STRUT AND AFT FLANGES. ASSUME TRIANGULAR DISTRIBUTION OF COMPRESSIVE STRESS WITH AN EQUIVALENT COMPRESSION LOAD CENTER $6\frac{1}{2}$ INCHES FROM THE TENSION LOAD CENTER. SEE SKETCH ON PAGE 10. THE LOAD IS DISTRIBUTED TO THE UPPER AND LOWER FLANGES IN INVERSE PROPORTION TO THE DISTANCE FROM THE TRUNNION CENTERLINE.

$$M_{℄ HORIZ.} = 36250(24.5) + 15430\,(7.688/2)$$
$$= 947.400 \text{ "\#}$$

NEGLECT RELIEVING MOMENT DUE TO DISTRIBUTED 77,340 #

TRUNNION

SECT. D-D. CONT.

TENSION LOAD TO UPPER FORWARD FLANGE

$$= \frac{6.375}{10.75} \times \frac{947400}{6.5} = 86500\#$$

(HORIZ. BENDING)

TENSION LOAD TO LOWER FORWARD FLANGE

$$= \frac{4.375}{10.75} \times 146000$$

$$= 59500\#$$

THE BENDING IN THE VERTICAL PLANE IS CARRIED BY A COUPLE AT THE UPPER AND LOWER FLANGE LOAD CENTERS.

NEUTRAL AXIS OF HALF CIRCLE

$$M_{VERT.} = 18800(24.5-2.35)$$

$$= 416{,}000''\#$$

TENSION LOAD TO LOWER FORWARD FLANGE (VERT BENDING)

$$= \frac{416000}{2 \times 10.75} = 19350\#$$

EQUIVALENT COUPLE LOAD IN SOCKET

$$= \frac{(21970-37600/2)(24.5)}{1/3(12.99-.39-.22)} = 18820\#$$

CHAMBER ON CYLINDER

TOTAL TENSION STRESS IN LOWER FORWARD FLANGE

$$f_t = \frac{59500 + 19350}{2.77} + \frac{18820}{18.0}$$

$$= 28500 + 1000 = 29{,}500 \text{ psi}$$

SHEAR IN LOWER FORWARD FLANGE-NEGLECT DISTRIBUTED LOAD FROM STRUT.

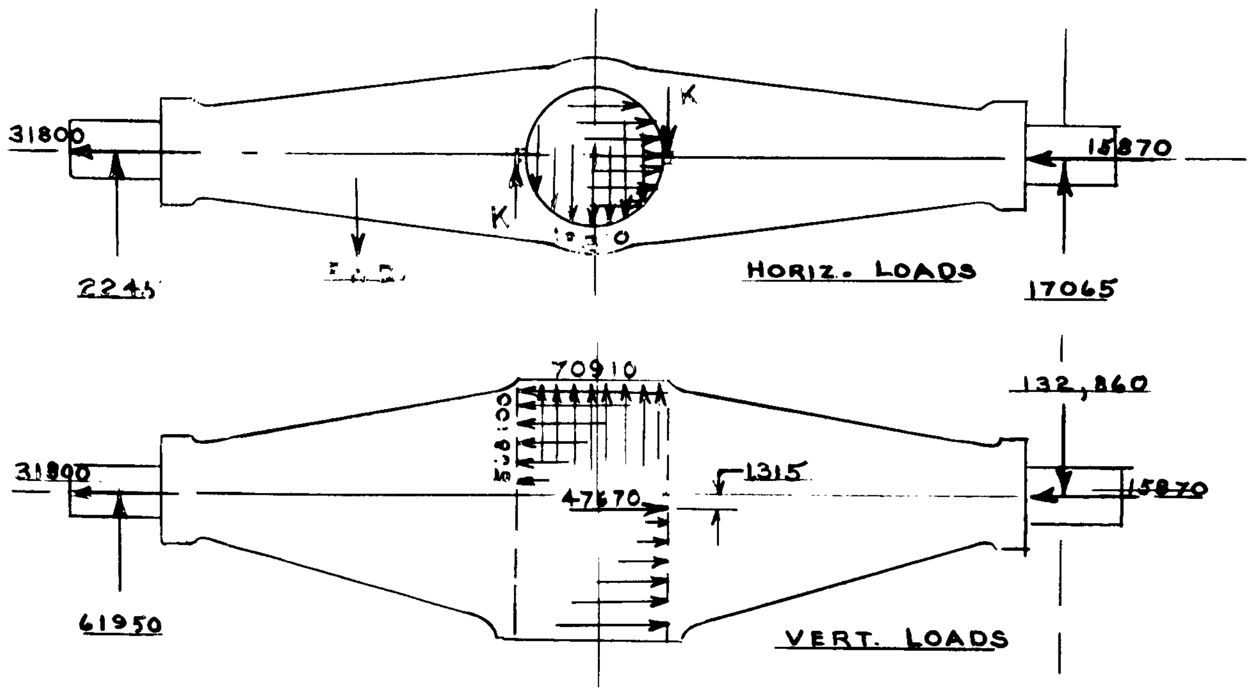
$$f_s = \frac{(36250 + 15430)(4.375/10.75)}{2.77}$$

$$= 7600 \text{ psi}$$

M.S. = HIGH

TRUNNION

SECT. D-D CONT'D.
COND. $10a_2$



THIS LOAD IS DISTRIBUTED OVER THE LENGTH OF THE SOCKET BUT IS SHOWN CONCENTRATED FOR CLARITY.

$$K = \frac{(17{,}065-2245)24.5}{7.688}$$
$$= 47{,}230\#$$

$$M_{HORIZ.} = 17065(24.5) - 47230(3.844)$$
$$= 236500''\#$$

Ref. Cond. $1a_2$ Pg. 8.11 for Method

TENSION LOAD TO UPPER FORWARD FLANGE (HORIZ. BENDING)

$$= \frac{6.375}{10.75} \times \frac{236500}{6.5} = 21550\#$$

EQUIVALENT COUPLE LOAD IN SOCKET

$$= \frac{(61950 + 79910/2)(24.5) - 31800(1.315)}{4.127}$$
$$= 568100\#$$

SIDE LOAD IN SOCKET = 47670 $S_a = 2/3(47670) = 31800\#$

$$M_{VERT} = 35{,}455 \times 22.15 = 785{,}000''\#$$

TENSION LOAD TO UPPER FORWARD FLANGE (VERT. BENDING)

$$= \frac{785000}{2 \times 10.75} = 36500\#$$

TRUNNION

SECT. D-D, CON'T.

TOTAL TENSION STRESS IN UPPER FORWARD FLANGE

$$f_t = \frac{21550 + 36500}{2.77} + \frac{568100 + 31800}{18.0}$$

$$= 21000 + 33300 = 54300 \text{ psi}$$

$$R_t = \frac{54300}{65000} = .835$$

$$f_s = \frac{(2245 + 47230)(6.375/10.75)}{2.77} + \frac{97405}{18.0}$$

$$= 10,590 + 5400 = 15,990 \text{ psi}$$

$$R_s = \frac{15,990}{39000} = .410$$

$$M.S. = \frac{1}{\left[(.835)^2 + (.410)^2\right]^{\frac{1}{2}}} - 1 = \underline{.07}$$

MAX. BEARING STRESS IN SOCKET

COND. 10_{b2} CRITICAL (NOTE: 53250 IS CONSERVATIVE BECAUSE $.8\ V_a = 49120\#$)

$$f_{br} = \frac{\left[61400(6.95) + 53250(88.367-1.315)\right] 6}{7.688(12.38)^2} + \frac{53250}{7.688(12.38)}$$

$$= 25800 + 560 = 26400 \text{ psi}$$

M.S. HIGH

TRUNNION

LIP OF TRUNNION COLLAR

MAX. VERTICAL LOAD FROM FORWARD TOWING COND.

$$Va = 45000\#$$
$$Da = 54000\#$$

DETAIL SPEC. LOAD-HIGHER THAN REQUIRED BY ANC-21

ASSUME FORWARD DEFLECTION OF 5 IN..

$$\overline{CE} = \left[45000(6.875-5)-54000(88,367-18.7)\right]\frac{1}{26.1}$$

$$= 140900\#$$

VERTICAL LOAD ON TRUNNION

$$= 45000 + 140900\ (\mathrm{SIN}\ 37\tfrac{1}{2}^{\circ})$$
$$= 45000 + 85700 = 130700\#$$

BEARING -- MIN. O.D. = 7.688-2x.22 = 7.248
MAX. I.D. = 7.072
AREA = .7854(7.248² - 7.072²)
= 1.98

$$f_{br} = \frac{130700}{1.98} = 66000 \text{ psi}$$

$$\text{M.S.} = \frac{124000}{1.5 \times 66000} - 1 = .25$$

SHEAR - AVE. DIAM. = 7.155
AREA = $\pi(7.155)(.37) = 8.32$

$$f_s = \frac{130700}{8.32} = 15700 \text{ psi}$$

M.S. HIGH

TRUNNION

8897-17 KEY 180000 H.T.

max. torque from cond. 10_{b2} Ref. Pg. 2.19

$$K = \frac{53250(6.875 + .385) + 13545(.6)}{7.688}$$

$$= 51340\#$$

ASSUME TRIANGULAR DISTRIBUTION

$$f_{br} = 2\left[\frac{51340}{11.56(4.215-3.845)}\right] = 24000 \text{ psi}$$

$$f_s = 2\left[\frac{51340}{11.56 \times .498}\right] = 17800 \text{ psi}$$

M.S. HIGH

TRUNNION

RETRACTING LOADS ON TRUNNION

THE RETRACT CYLINDER PRODUCES TORQUE ON THE R. H. SIDE OF THE TRUNNION. THIS TORQUE IS CARRIED BY THE I SECTION WHICH IS ASSUMED FIXED AT BOTH ENDS. (NO WARPING, PLANE SECTIONS REMAIN PLANE) THE TORQUE IS CARRIED OVER 19.188 INCHES BUT THE DISTANCE BETWEEN FIXED ENDS IS TAKEN AS 12.2 INCHES. THIS CORRESPONDS TO A DISTANCE FROM $1\frac{1}{2}$ INCHES INBOARD OF SECT. C-C TO $1\frac{1}{2}$ INCHES OUTBOARD OF SECT. B-B. AT THE SECTIONS ADJACENT TO THE FIXED ENDS THE TWISTING MOMENT IS BALANCED BY HORIZONTAL TRANSVERSE SHEAR IN THE FLANGES. IT WILL BE CONSERVATIVELY ASSUMED THAT ALL THE TORQUE ALONG THE BEAM IS CARRIED BY DIFFERENTIAL BENDING. SINCE THE FLANGES VARY IN WIDTH THE POINT OF INFLECTION WILL NOT BE AT MID-LENGTH. THE INFLECTION POINT IS DETERMINED AS THAT WHERE SLOPE OF THE ELASTIC CURVE OF THE FLANGE IS A MAXIMUM. FOR A CANTILEVER BEAM THE END SLOPE IS PROPORTIONAL TO L^2/I. THE RATIO OF THE LENGTHS FROM THE FIXED ENDS TO THE INFLECTION POINT IS THEREFORE DIRECTLY PROPORTIONAL TO THE SQUARE ROOT OF THE MOMENTS OF INERTIA.

DOUGLAS AIRCRAFT COMPANY, INC.

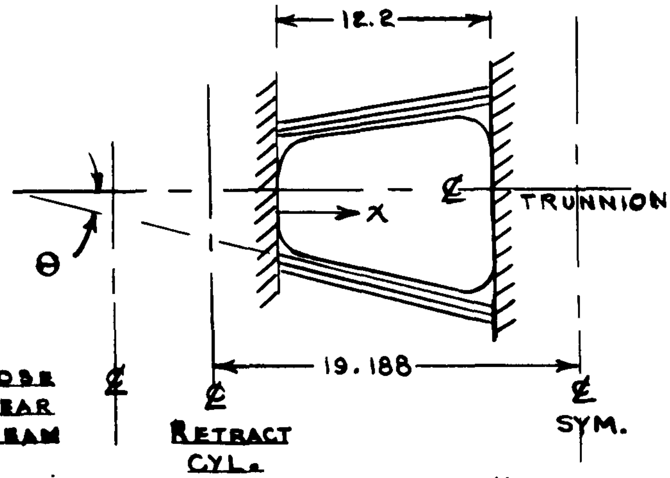
PREPARED BY: HAMMIL
DATE: 5-27-49
TITLE: NOSE GEAR

6B PLANT

PAGE: 8.18
MODEL: C-124A
REPORT NO. 10351

TRUNNION

RETRACTING LOADS-CONTD.



MOMENT OF INERTIA-FLANGE ONLY

STA.	FLANGE WIDTH	I	$\sqrt{I}$
X=0	5.25	7.9	2.81
2	5.67	10.0	3.16
4	6.09	12.7	3.56
6	6.50	15.7	3.96
8	6.83	18.5	4.30
10	7.34	23.2	4.82
12.2	7.85	29.0	5.38

ASSUME LINEAR VARIATION

$$\sqrt{I} = 2.8 + .20\,X$$

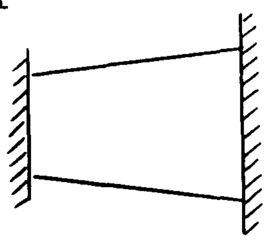
L_1 = DIST. FROM X=0 TO INFLECTION PT.

$$\sqrt{I_1} = \frac{2.8 + .20L_1 + 2.8}{2} = 2.8 + .10L_1$$

$$L_2 = 12.2 - L_1$$

$$\sqrt{I_2} = \frac{2.8 + .20L_1 + 2.8 + .20(12.2)}{2}$$

$$= 4.01 + .10L_1$$

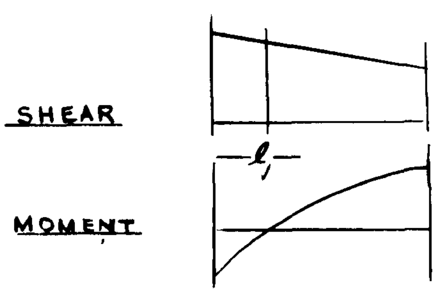


$$L_1\sqrt{I_2} = L_2\sqrt{I_1}$$

$$L_1(4.01 + .10L_1) = (12.2-L_1)(2.8+.10L_1)$$

$$L_1^2 + 27.95L_1 - 170.8 = 0$$

$$L_1 = 5.16$$



MAX. TORQUE FROM RETRACT COND. (GEAR UP)

$$T = 47300 \times 6.72 = 31800\#''$$

FLANGE SHEAR $= T/h = 31800/h$

	X=0	X = L_1 = 5.16	X= 12.2
h	5.5	7.75	11.0
v	57800	41000	28900

TRUNNION

RETRACTING LOADS-CONTD.

MOMENT AT X =0, LOWER FLANGE, COS θ = .967

$$M_y = \left(\frac{41000 + 57800}{2}\right)\left(\frac{5.16}{.967}\right)$$

$$= 263500''\#$$

ALLOWABLE BENDING MOMENT FROM PG. 8.08, COL. (5)

$$M_y = 662000/2 = 331000''\#$$

$$R_y = .795$$

REACTIONS AT NOSE GEAR BEAM

$$R_a = \left(\frac{19.188 + 24.5}{49}\right) 47300 = 42170$$

$$R_b = 5130\#$$

REACTIONS ARE 9° FROM AXES OF TRUNNION

$$M_y = (5130)(\text{SIN } 9)(24.5 + 4.0 + 12.2)$$
$$= 32700''\#$$

$$R_y = \frac{32700}{662000} = .049$$

$$M_x = (5130)(\text{COS } 9)(40.7)$$

$$= 206000''\#$$

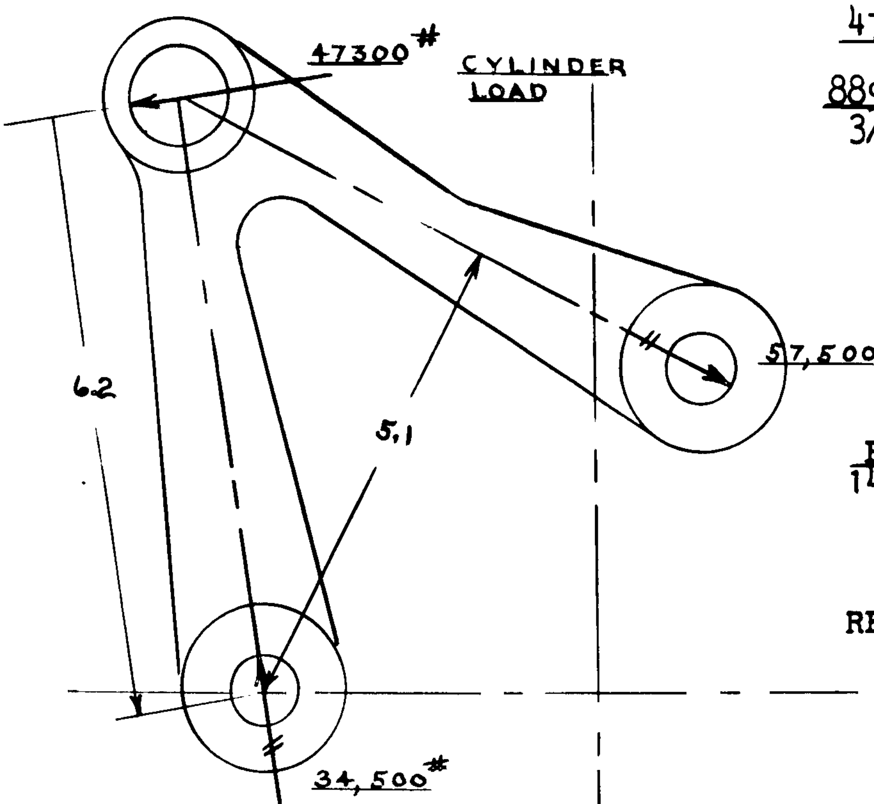
$$R_x = \frac{206000}{2260000} = .091$$

$$\text{M.S.} = \frac{1}{.795 + .049 + .091} - 1 = \underline{\underline{.07}}$$

TRUNNION

RETRACTING ARM -8897A-14A-6

CRITICAL WITH GEAR UP AS SHOWN-RETRACT COND.



$$\frac{47300 \times 6.2}{5.1} = 57500\#$$

8897A-19 BOLT
3/4 IN. BOLT -160000 H.T.

$P_{a_s} = 2 \times 41950$

$$M.S. = \frac{83900}{1.15 \times 57500} - 1 = \underline{\underline{.27}}$$

BEARING
14ST FORGING LUG

$P_a = 2(.844)(.745)(9800)$
$= 123100$

RETRACTING ARM

$P_a = (.747)(.745)(200000)$
$= 111300$

$$M.S. = \frac{111300}{1.5 \times 57500} - 1 = \underline{\underline{.29}}$$

SHEAR OUT

14S FORGING $\quad f_s = \frac{57500}{2(.844)(.505)2} = 34000$ psi

ARM $\quad f_s = \frac{57500}{2(.747)(.475)} = 81000$ psi

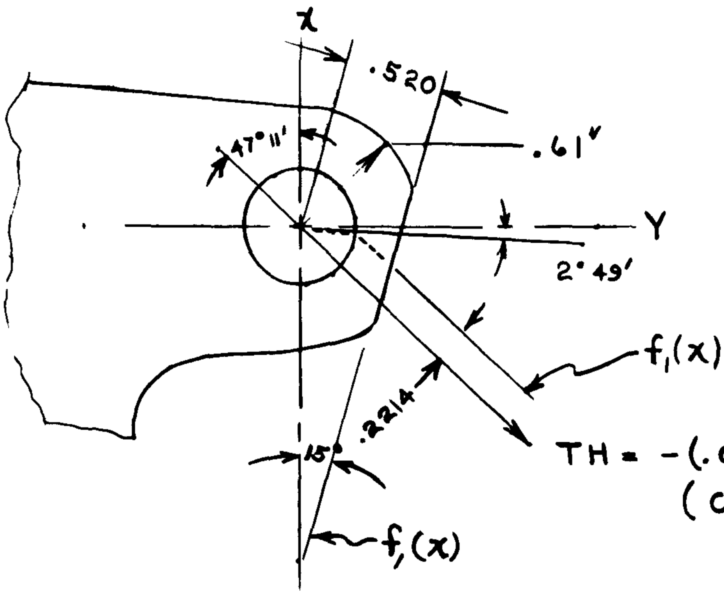
$$MS = \frac{105000}{1.15 \times 81000} - 1 = \underline{\underline{.13}}$$

$$= \frac{39000}{1.15 \times 34000} - 1 = \underline{0}$$

TRUNNION

DOWN LOCK LINK LUG

AL. ALLOY -14ST
65,000 MIN. T.S.



TH = −(.07955)(−152,890) = 12,200#
(COND. 11 − P 3.07, 3.09)

SHEAR OUT

$X^1 = \boxed{(R_2^1)^2 - .41318(R_1^1)^2}^{\frac{1}{2}} - .76604\, R_1^1$

$R_2^1 = .61"; \; R_1^1 = .3445$

$X^1 = .3045$

TO GET R_2'',

$G_1 = f_1(X) = -26795x + .5384$

$G_2 = f_2(X) = 107927x + .3258$

$G_1 = G_2 = .4961$

$X^1 = .1578$

$R_2'' = \boxed{X^2 + y^2}^{\frac{1}{2}} = .5206; \; R_1'' = .3445$

$X'' = .2073$

$A_s = (.3045 + .2073)(.746) = .3818 \text{ IN}^2$

$f_s = \frac{12,200}{.3818} = 32,000$ psi

$F_s = 39,000$ psi MS $= \frac{39000}{32000 \times 1.15} - 1 = \underline{.060}$

CONTRACTOR'S

STRESS ANALYSIS

OF

CONTRACTOR'S DESIGN ALTERNATIVE "A"

(Dwg. #CP-529)

REDESIGN

OF

DOUGLAS NOSE LANDING GEAR TRUNNION

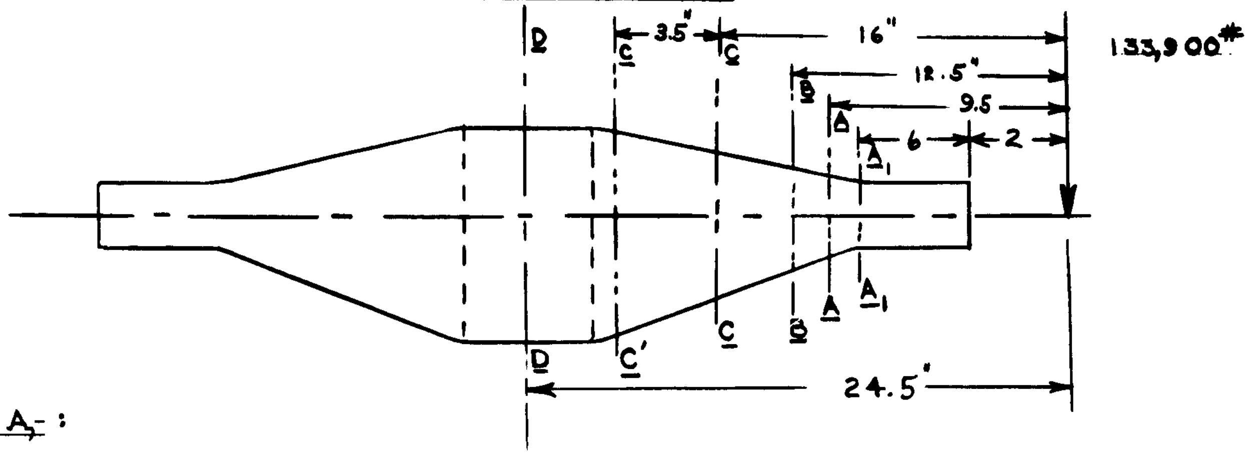
PART NO. 8897B-114

(Redesigned from an "I" Section Aluminum Forging
to a "Tublarform" High-Strength Steel Casting)

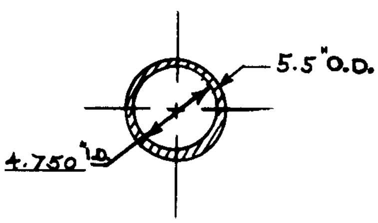
(Approximate Weights, Original and Redesign, 85 pounds)

ALLOY ENGINEERING & CASTING COMPANY
CHAMPAIGN, ILLINOIS

SET "A"
DOUGLAS NOSE GEAR TRUNNION DESIGN CALCULATIONS



SECTION - A_1 :



AREA AT SECTION $\frac{\pi}{4}(5.5^2 - 4.750^2) = 6.01 \text{ IN}^2$

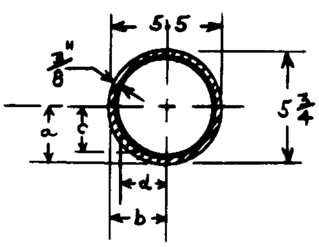
$I = 0.049\,(D_o^4 - D_i^4) = 0.049(5.5^4 - 4.750^4) = 20.1 \text{ IN}^4$

$M = 133{,}900\# \times 8" = 1{,}070{,}000$ in-lb.

$C = \frac{D_o}{2} = 2.75"$

$S = \frac{MC}{I} = \frac{1{,}070{,}000 \times 2.75}{20.1} = \underline{146{,}500} \text{ psi}$

SECTION - A :



AREA AT A $= \frac{\pi}{4}(5.500^2 - 4.750^2) + 2\left(\frac{3}{8} \times \frac{1}{4}\right) = 7.885 \text{ IN}^2$

ASSUME OVAL SECTION FOR STRESS CALC.

$I = 0.7854\,(a^3b - c^3d) = 0.7854\,(2.875^3 \times 2.750 - 2.500 \times 2.375)$

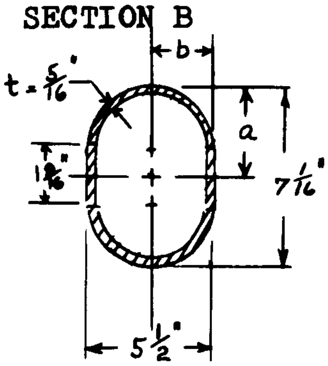
$I = 22.3 \text{ IN}^4$

$C = a = 2.875$ IN

$M = 133{,}900\# \times 9.5" = 1{,}270{,}000$ in-lb.

$S = \frac{MC}{I} = \frac{1{,}270{,}000 \times 2.875}{22.3} = \underline{164{,}000} \text{ psi}$

SECTION B



AREA AT B $= \frac{\pi}{4}(5.500^2 - 4.875^2) + 2\left(\frac{5}{16} \times 1.563\right)$

$= 7.125 \text{ in}^2$

$I = \frac{\pi}{4} a^2(a + 3b)t = \frac{\pi}{4} \times 3.531^2(3.531 + 3 \times 2.75)$

$0.313 = 34.0 \text{ IN}^4$

ASSUMING OVAL SECTION & NEUTRAL AXIS THRU CENTER OF SECTION.

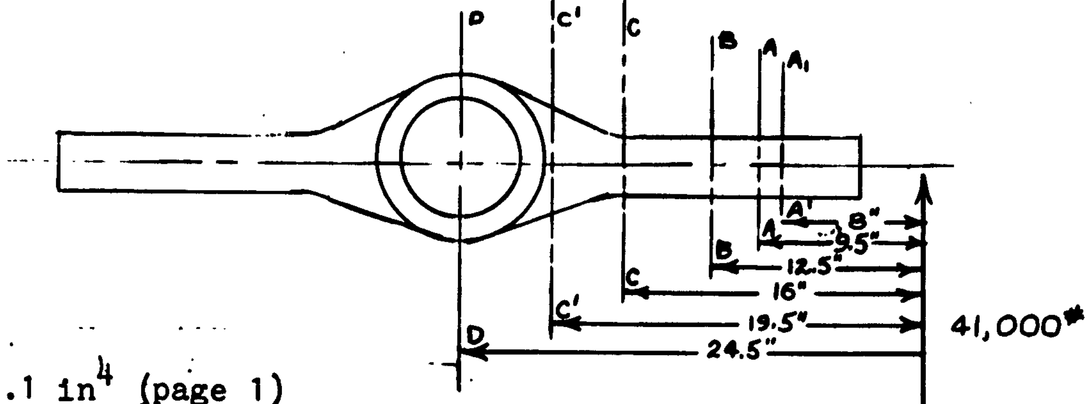
$C = a = 3.531"$

$M = 133{,}900\# \times 12.5" = 1{,}675{,}000$ in-lb.

$S = \frac{1{,}675{,}000 \times 3.531}{34.0} = \underline{174{,}000 \text{ psi}}$

SET "A"

HORIZONTAL BENDING



SECTION-A

$I = 20.1 \text{ in}^4$ (page 1)
$M = 41{,}000 \times 8 = 328{,}000$ in-lb.
$C = 2.75$ in.
$S = \dfrac{328{,}000 \times 2.75}{20.1} = \underline{\underline{44{,}800}}$ psi

SECTION-A

$I = \frac{\Pi}{4} a^2(a + 3b)t = \frac{\Pi}{4} 2.75^2(2.75+3\times2.875).375 = 25.4 \text{ in}^4$
$C = 2.75$ in.
$M = 41{,}000 \times 9.5 = 390{,}000$ in-lb.
$S = \dfrac{390{,}000 \times 2.75}{25.4} = \underline{\underline{42{,}500}}$ psi

SECTION-B

$I = \frac{\Pi}{4} 2.75^2 (2.75+3\times3.531)0.3125 = 24.8 \text{ in}^4$
$C = 2.75$ in.
$M = 41{,}000 \times 12.5 = 512{,}500$ in-lb.
$S = \dfrac{512{,}500 \times 2.75}{24.8} = \underline{\underline{56{,}800}}$ psi

SECTION-C

$I = \frac{\Pi}{4} 2.75^2(2.75+3\times4.875)0.250 = 25.8 \text{ in}^4$
$C = 2.75$ in
$M = 41{,}000 \times 16 = 656{,}000$ in-lb.
$S = \dfrac{656{,}000 \times 2.75}{25.8} = \underline{\underline{70{,}000}}$ psi

SECTION-C

$I = \frac{\Pi}{4} 3.250^2(3.250+3\times6.188)0.250 = 45.4 \text{ in}^4$
$C = 3.250$ in
$M = 41{,}000 \times 19.5 = 800{,}000$ in-lb.
$S = \dfrac{800{,}000 \times 3.250}{45.4} = \underline{\underline{57{,}300}}$ psi

SET 'A' 4

HORIZONTAL BENDING

SECTION-D

MOMENT OF INERTIA OF ONE RECTANGULAR SECTION = $\frac{BH^3 - bh^3}{12} = \frac{\cdots \times 1.375^3 - 12.5 \times 0.875^3}{12} = 2.12 \text{ in}^4$

By Parallel axis

AREA OF SECTION 6.95 in^2 (approx.)

I = 2.12 + 6.95 x ..438^2 = 13..12 in^4

I of section D = 13..12 x 2 = 270.24 in^4

M = 41,000 x 24.. = 1,00.,000 in-lb.

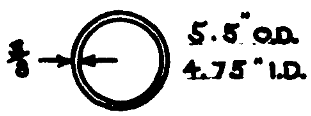
C = ..125 in

S = $\frac{1,005,000 \times \ldots}{270}$ = ..,500 psi

CP-554

SET "C"
VERTICAL BENDING

SECTION "A"$_1$



AREA = 6.04 IN^2

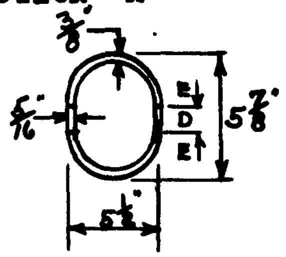
$I = 20.1$ IN^4

$M = 133{,}900 \times 8 = 1{,}070{,}000$ IN.#

$C = 2.75$

$S = \dfrac{1{,}070{,}000 \times 2.75}{20.1} = 146{,}500$

SECTION "A"



AREA ZONE E = 6.04 IN^2

AREA ZONE D = .23 IN^2

TOTAL = 6.27 IN^2

ASSUME OVAL SECTION WITH CONSTANT WALL

$I = .785(2.94^3 \times 2.75 - 2.57^3 \times 2.38)$

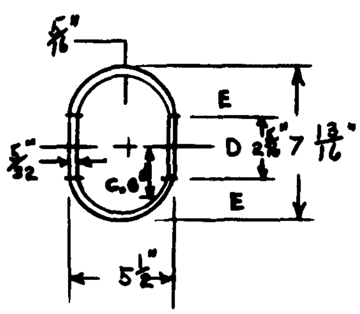
$= 23.2$

$C = 2.94$ IN^4

$M = 133{,}900 \times 9.5 = 1{,}270{,}000$ IN#

$S = \dfrac{1{,}270{,}000 \times 2.94}{23.2} = \underline{161{,}000 \text{ psi}}$

SECTION "B"



AREA ZONE E = 5.10 IN^2

AREA ZONE D = .72 IN^2

TOTAL = 5.82 IN^2

$d = 2.83$

$I_c = 2.55 \times 2.83^2 \times 2 = 40.8$ IN^4

$I_d =$ NEGLECT

$M = 1{,}675{,}000$

$C = 3.9$

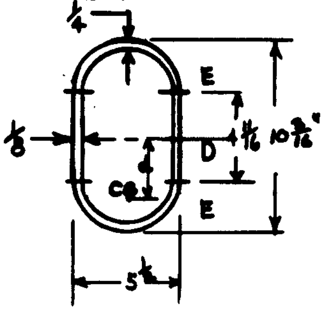
$S = \dfrac{1{,}675{,}000 \times 3.9}{40.8} = \underline{160{,}000 \text{ psi}}$

CP-554

SET "C"

VERTICAL BENDING

SECTION "C"



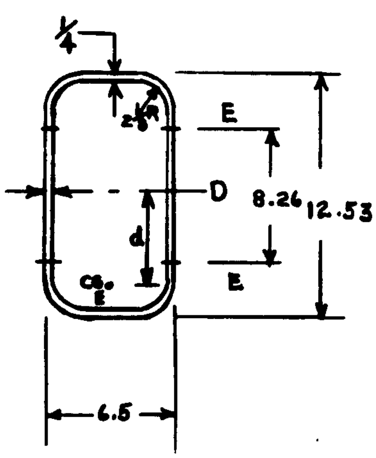
AREA ZONE E = 4.12 IN^2
AREA ZONE D = 1.17 IN^2
TOTAL = 5.29 IN^2

$d = 4.04$
$I_e = 2.06 \times 4.04^2 \times 2 = 67.2\ IN^4$
$I_d = \frac{1}{12} \times .25 \times 4.68^3 = 2.13\ IN^4$

$I_e + I_d = 69.33\ IN^4$
$M = 2,140,000\ IN^4$
$C = 5.09\ IN$

$S = \frac{2,140,000 \times 5.09}{69.33} = \underline{\underline{157,500\ psi}}$

SECTION "C"



AREA ZONE E = 4.26 IN^2
AREA ZONE D = 2.07 IN^2
TOTAL = 6.33 IN^2

$d = 5.58$
$I_e = 2.13 \times 5.58^2 \times 2 = 132.5$
$I_d = \frac{1}{12} \times .25 \cdot 8.26^3 = 11.8$
$I_e + I_d = 144$
$M = 2,610,000$
$C = 6.27$
$S = \frac{2,610,000 \times 6.27}{144} = \underline{\underline{113,500\ psi}}$

SET "C" 4

SECTION "A" 1

HORIZONTAL BENDING

AREA = 6.04 IN^2
$I = 20.1\ IN^4$
$M = 41{,}000 \times 8 = 328{,}000$ IN#
$C = 2.75$
$S = \dfrac{328{,}000 \times 2.75}{20.1} = \underline{44{,}800 \text{ psi}}$

SECTION "A"

AREA ZONE E = 6.04 IN^2
AREA ZONE D = .23 IN^2
TOTAL = 6.17 IN^2

$I_e = 20.1\ IN^4$
$I_d = .23 \times 2.60^2 = 1.5$
$I_e + I_d = 21.6$
$M = 41{,}000 \times 9.5 = 390{,}000$
$C = 2.75$
$S = \dfrac{390{,}000 \times 2.75}{21.6} = \underline{49{,}700 \text{ psi}}$

SECTION "B"

AREA ZONE E = 5.10 IN^2
AREA ZONE D = .72 IN^2
TOTAL = 5.82 IN^2

I_e = ASSUME 5 O.S. WITH $\frac{5}{16}$ WALL = 12.7
$I_d = 2 \times .36 \times 2.69^2 = 5.2$
$I_e + I_d = 17.9$
$M = 512{,}500$
$C = 2.75$
$S = \dfrac{512{,}500 \times 2.75}{18} = \underline{78{,}500 \text{ psi}}$

CP-554

SET "C"
HORIZONTAL BENDING

SECTION "C"

AREA ZONE E = 4.12 IN^2
AREA ZONE D = 1.17 IN^2
TOTAL = 5.29 IN^2

I_e = ASSUME 5 1/4 DIA WITH 1/4 WALL
= 12.3
$I_d = 2 \times .585 \times 2.69^2 = 8.46$
$I_e + I_d = 20.8$
$C = 2.75$
$M = 656{,}000$
$S = \dfrac{656{,}000 \times 2.75}{20.75} = \underline{87{,}000}$ psi

SECTION "C"[1]

AREA ZONE E = 4.26
AREA ZONE D = 2.07
TOTAL = 6.33

I_e = ASSUME OVAL $6\frac{1}{2} \times 4\ 1/4$ WITH 1/4 WALL
= 53

$I_d = 2 \times 1.04 \times 3.18^2 = 21$
$I_e + I_d = 64$
$M = 800{,}000$
$C = 3.25$
$S = \dfrac{800{,}000 \times 3.25}{64} = \underline{41{,}000}$ psi

SECTION "D"

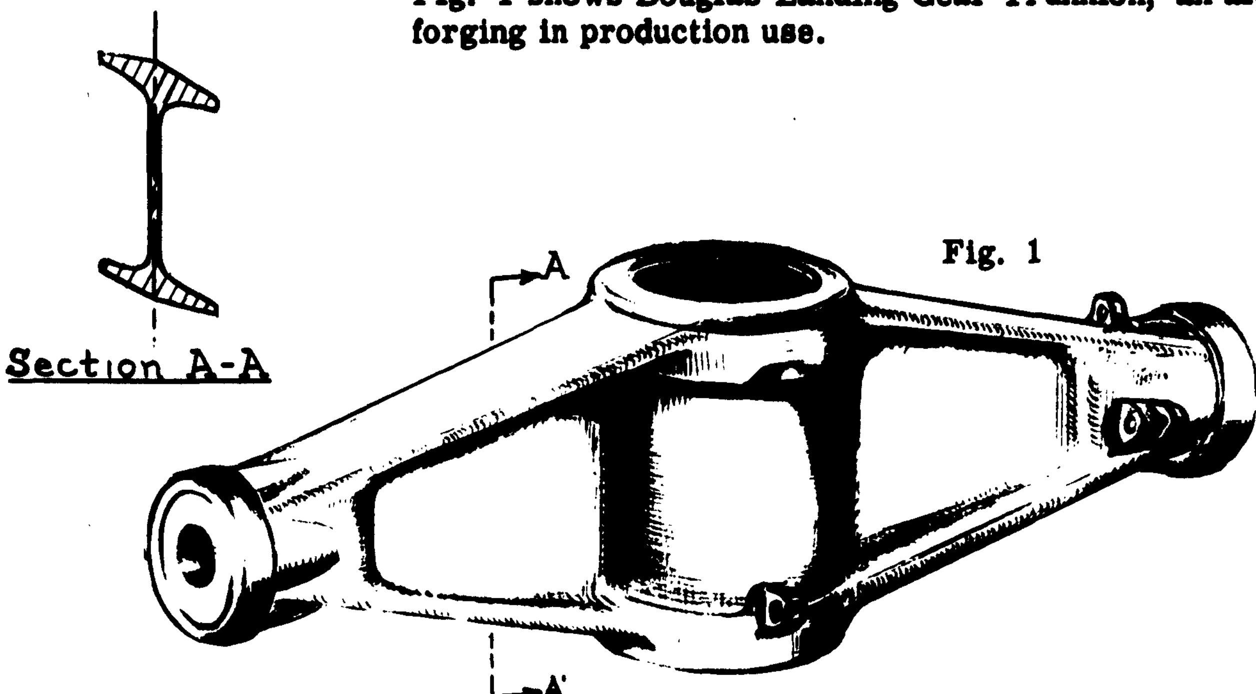
AREA ZONE E = 4.76
AREA ZONE D = 4.32
TOTAL = 9.08

$I_e + I_d = 2 \times 4.54 \times 4.43^2 = 178$
$M = 1{,}005{,}000$
$C = 5.125$
$S = \dfrac{1{,}005{,}000 \times 5.125}{178} = \underline{28{,}800}$ psi

CP-554

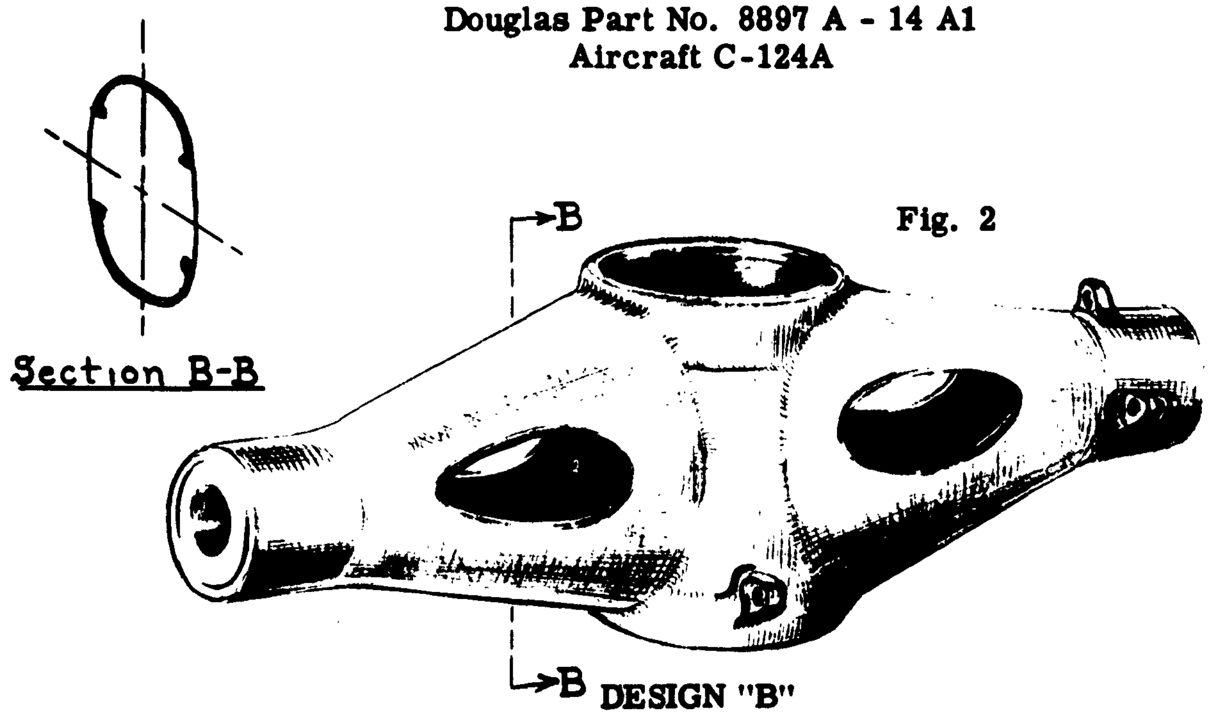
Fig. 1 shows Douglas Landing Gear Trunnion, an aluminum forging in production use.

Fig. 1



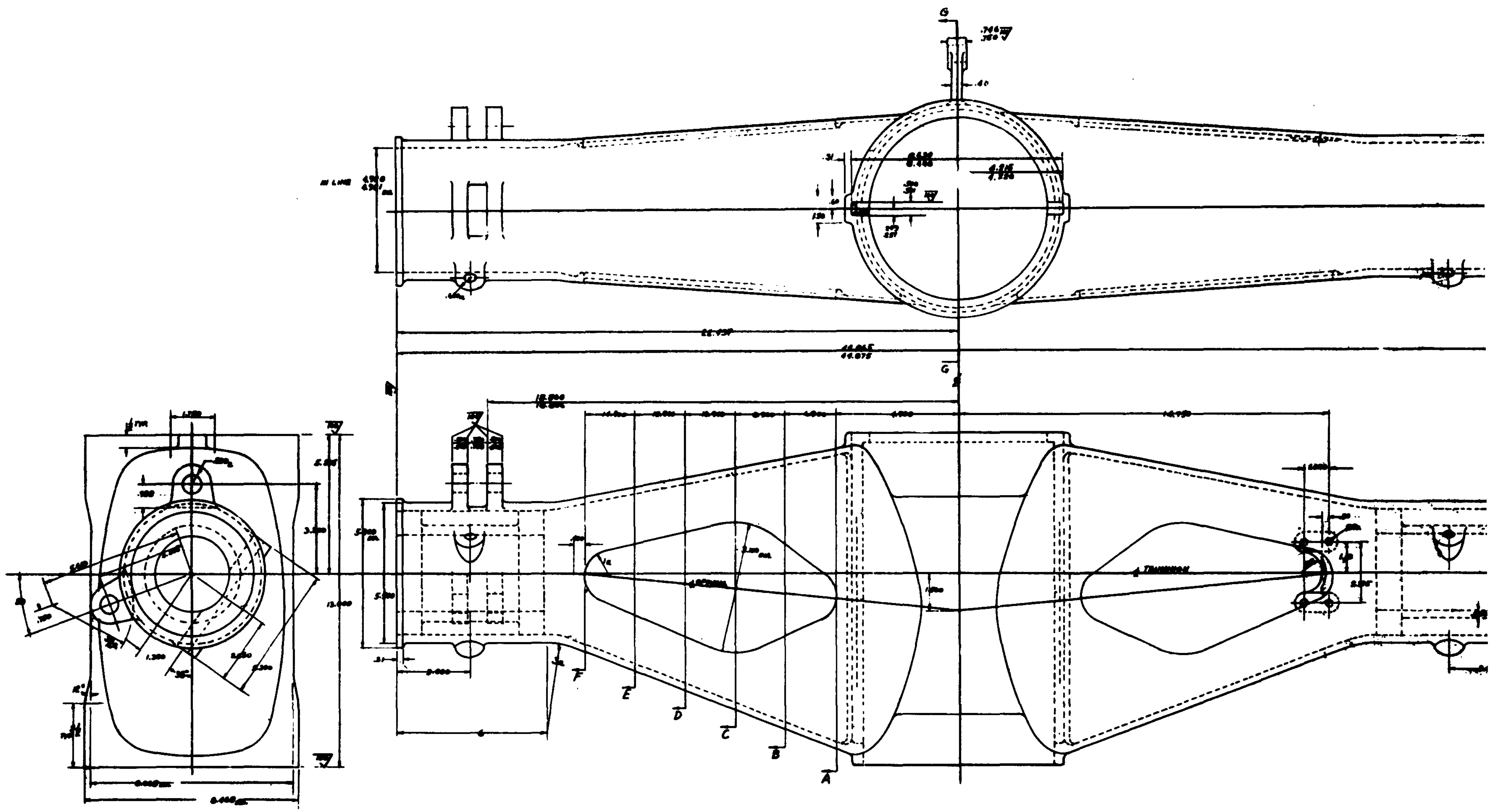
ORIGINAL ALUMINUM FORGING
DOUGLAS TRUNNION
Douglas Part No. 8897 A - 14 A1
Aircraft C-124A

Fig. 2



DESIGN "B"
Redesigned for Casting
DWG. No. CP-566

Fig. 2 shows Contractor's Design Alternate B, a redesign for production as a high-integrity, heat treated alloy steel casting. Casting design is based on 170,000 psi ultimate, considered a conservative figure. Weights of the forged and cast parts are approximately equal. Aluminum end bushings are employed in both designs. Wall section through trunnion arms at B-B tapers from .150" to .253".

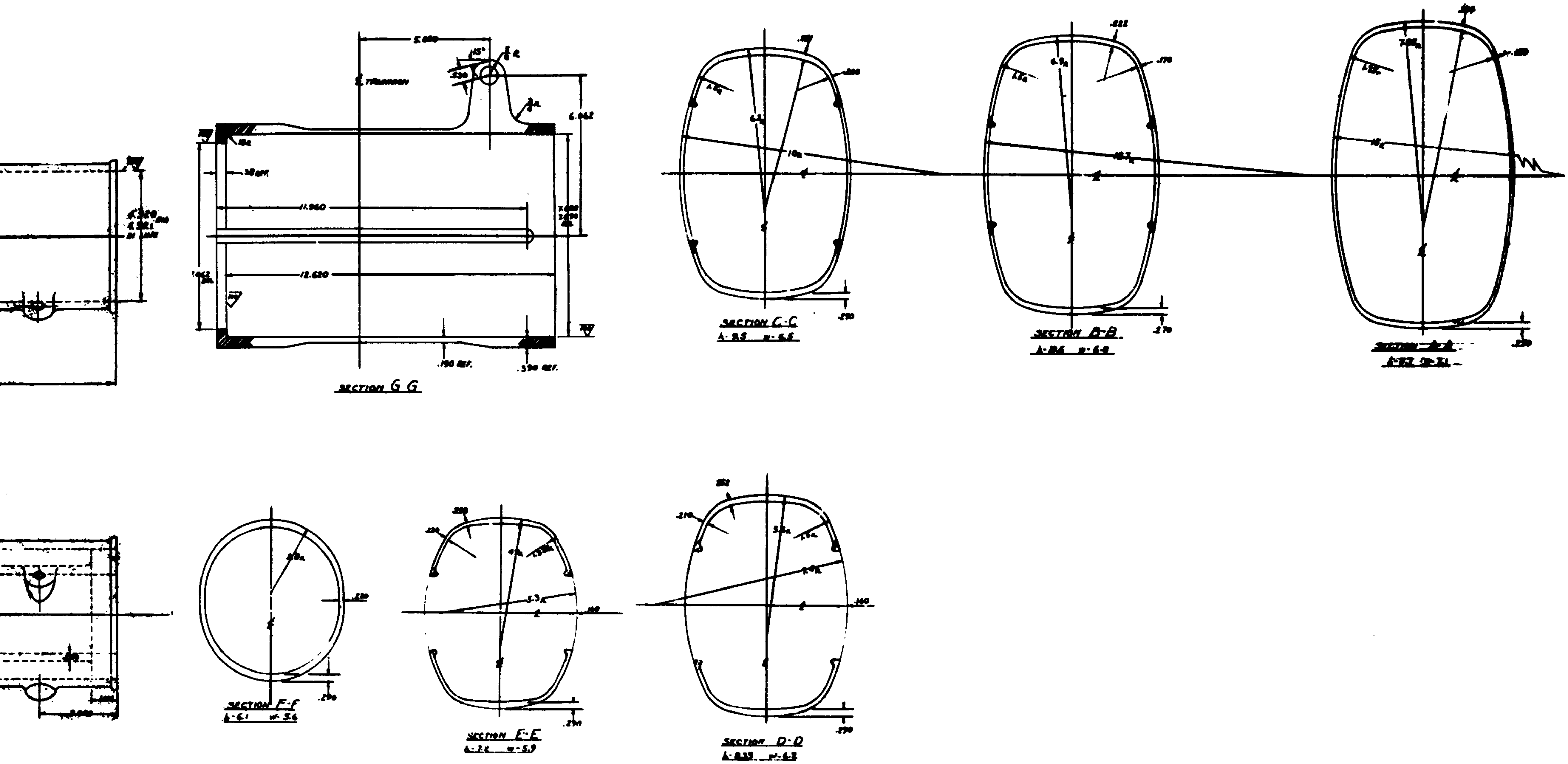


DESIGN ALTERNA

DOUGLAS C-124A NOSE LANDI

REDESIGNED AS "TUBLARFORM" HIGH-STRENGTH STEEL

REDESIGNED FROM DOUGLAS PART NO. 8807



DOUGLAS TRUNNION

HEAT TREAT: 170,000 P.S.I.
WEIGHT: 8.5 LBS.

ALLOY ENGINEERING & CASTING CO.

A CP-566

FULL

ALTERNATIVE B.
OSE LANDING GEAR TRUNNION
TH STEEL CASTING. A.E.C.CO. Dwg. NO. CP-566.
NO. 8807A-15-F, ALUMINUM FORGING

CONTRACTOR'S

STRESS ANALYSIS

OF

CONTRACTOR's DESIGN ALTERNATIVE "B"

(Dwg. #CP-566)

REDESIGN

OF

DOUGLAS NOSE LANDING GEAR TRUNNION

PART NO. 8897B-114

(Redesigned from an "I" Section Aluminum Forging
to a "Tublarform" High-Strength Steel Casting)

(Approximate Weights, Original and Redesign, 85 pounds)

ALLOY ENGINEERING & CASTING COMPANY
CHAMPAIGN, ILLINOIS

MARGIN OF SAFETY TABLE

PAGE	TITLE	TYPE OF STRESS	NET MARGIN OF SAFETY
A	INTRODUCTION		
2	ALUM. SPACER	BEARING	.085
3	SEC. G-G	COMBINED BEND.	.050
5	SEC. F-F	COMBINED BEND. SHEAR	.018 .020
7	SEC. E-E	COMBINED BEND.	.050
9	SEC. D-D	COMBINED BEND.	.040
11	SEC. C-C	COMBINED BEND.	.005
13	SEC. B-B	COMBINED BEND.	.020
16	SEC. A-A	COMBINED BEND.	.020
23	SEC. H-H	COMBINED TENS. & SHEAR	.055
26	RETRACT. LUGS	BEARING	.270
27	WEIGHT SUMMARY		

Date 4-3-53

1. The following pages contain the stress analysis of the Douglas Nose Beam Aluminum Trunnion (8897B-114) designed as a 4340 - XXX steel casting heat treated to 170,000 psi.

2. The object of this analysis is to justify the use of a steel casting for a large structural member.

3. The strength weight ratio of the steel casting is practically the same as the aluminum forging (approximately 85 lbs.). See the weight breakdown shown on page 27 of this report.

4. In order to keep the weight to a minimum, it was necessary to assume that the following criteria would be adhered to by good technical and quality control.

   a. High standards of tolerances, surface control, elongation, mechanical properties, quality of control and X-ray control.

   b. Elimination of the casting factor. If a casting factor is necessary, it is suggested that it be obtained in the actual test of the trunnion and not during the initial design.

5. As shown on page 1, check stations were taken at practically every two (2) inches of the length of the casting in order to insure optimum design. The margins of safety were kept to a minimum.

6. The geometric cross sectional shape of the casting was chosen to afford the maximum amount of material being concentrated at the outermost fibres for the highest bending moments. The sections were also curved in order to increase the buckling strength of the material.

7. Pages 17 and 18 contain

   a. Bending modulus of rupture curves

   b. Allowable crippling curve (limited by D/t)

   These curves are presented to show that the trapizoidal distribution as established by the modulus of rupture curves cannot be attained because the sections are limited by local crippling. In this case there will be a minimum amount of yielding of the outermost fibres and, therefore, the unsymmetrical bending distribution shown in <u>Niles and Newell, Vol I</u> is used throughout this analysis.

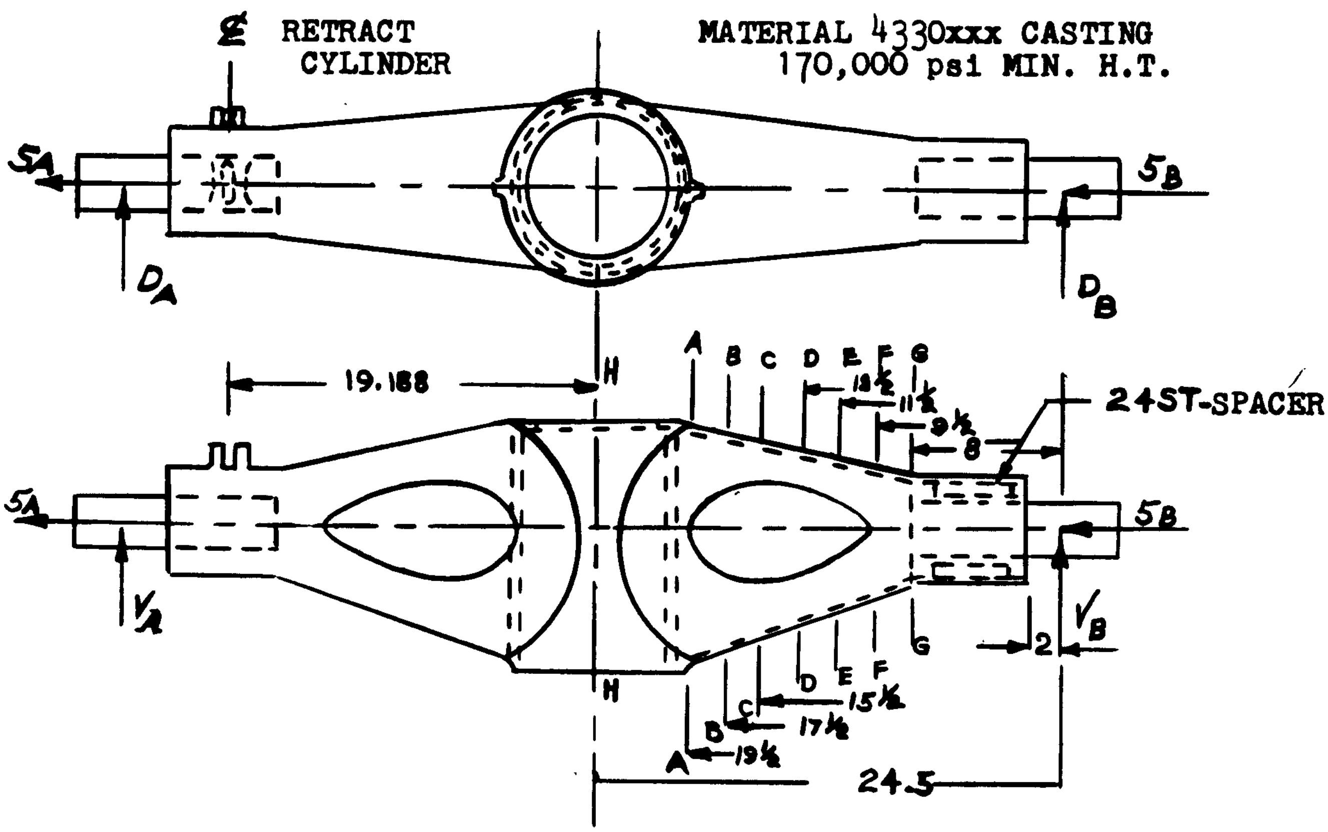
Date 4-3-53

8. A uniform equivalent thickness of element No. 1 only was used in order to obtain the correct section properties. The actual area of element No. 1 was calculated using the average thickness.

9. The cutout in the sides of the webs were made with the sides of the rectangles closer to 45° to the neutral axis than parallel to the neutral axis. This diamond shape shows the least stress concentration factor and smaller areas of high stress. The shear stress concentration factor used was 1.5 and the critical section for shear is FF, page 5.

CB
~~3-23-53~~

TRUNNION



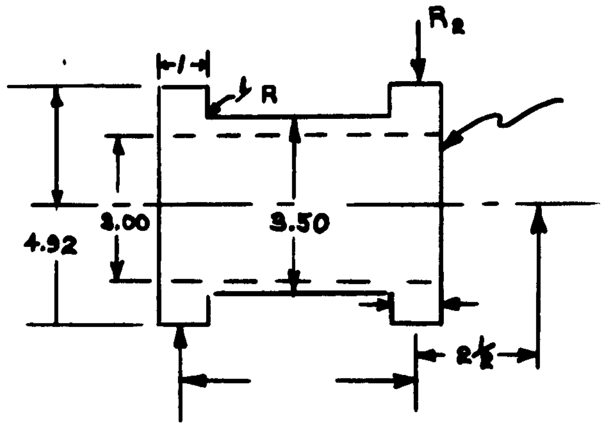
CRITICAL LOAD CONDITIONS REF PG 8.01 LB RPT10351

	COND 1a(2)	COND 10a(2)	COND 10b(2)
Va Da	21970 41090	61950 2245	79255 1285
Vb Db	15630 36250	-132860 17065	-130,260 14830
S ($S_a + S_b$)	0	47670	53250

( )

Date 3-23-53

SPACER-ALUM.



$$R_1 = \frac{133900 \times 2.5}{4.85} = 69100 \text{ lbs.}$$

$$R_2 = 13900 + 69100 = 203{,}000 \text{ lbs.}$$

$$f_{br} = \frac{203000}{3 \times 1.25} = 54100 \text{ psi}$$

1" + 1/4" RADIUS = 1.25 IN

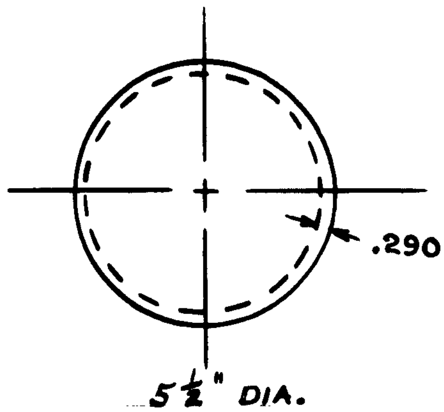
$$f_{br} = \frac{203000}{4.92 \times 1.0} = 41200 \text{ psi}$$

$$f_{br} = 118000 \text{ psi}$$

BEARING FACTOR - 2

$$M.\ S. = \frac{118000}{54100 \times 2} - 1 = \boxed{.085}$$

Date 3-23-53



SECT. G-G

$A = .7854\ (5.50^{-2} - 4.92^{-2}) = 4.80\ IN^2$

$Q = .0833\ (5.50^3 - 4.92^3) = 3.92\ IN^3$

$I = .049\ (5.50^4 - 4.92^4) = 15.70\ IN^4$

$b = .580\ IN$

CRITICAL COND. 10a (2) (REF PG 1)

MAX V_b = -132860 lbs.

D_b = 17065 lbs.

S_b = 2/3 (47670) = 31800 Lbs.

$MOMENT_{xx}$ = 132860 x 8 = 1,065,000 IN lb.

$MOMENT_{yy}$ = 17065 x 8 = 137,000 IN lb.

R mom. = $(1{,}065{,}000^2 + 137{,}000^2)\ 1/2$ = 1,070,000 IN lb.

$f_b = mc/I = \frac{1{,}070{,}000 \times 2.75}{15.70} = 188{,}000$ psi

$f_c = S/A = \frac{31800}{4.80} = 6620$ psi

D/t = 19 F_b/F_{tu} = 1.21 FIG 2.321 ANC-5

$F_b = 1.21 \times 170{,}000 = 206{,}000$ psi

$F_c = 170{,}000$ psi

$R_b = .912$

$R_c = .039$ M.S. $= \frac{1}{R_b + R_c} - 1 = \boxed{.05}$

MAX. SHEAR (FWD. SECT. G-G) SEE PG2

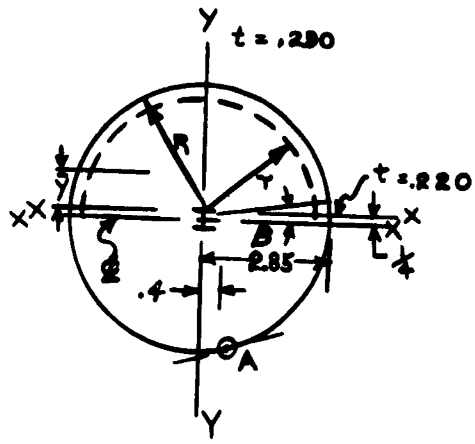
S = 210,000 lbs.

$f_{su} = SQ/I_b = \frac{210{,}000 \times 3.92}{15.70 \times .580} = 90{,}200$ psi

$f_{su} = 100{,}000$ psi M.S. $= \frac{100{,}000}{90200} - 1 = \boxed{.11}$

Date 3-23-53

SECT. F-F



$\bar{y} = .4244 \left(R^2 + \frac{r^2}{R+r}\right)$ R=2.80 r=2.53 $t_{equiv.}$ = .270

$\bar{y} = .4244 \left(2.80 + \frac{6.88}{5.35}\right) = 1.70$

$A = \pi/2 \, (R^2 - r^2) = \frac{3.1416}{2} = (7.85 - 6.38)$

$= 2.31 \text{ IN}^2$

$I_{xx} = I_{yy} = \pi/8 \, (R^4 - r^4)$

$I_o = I_{xx} - (y^2 A)$ $= \frac{3.1416}{8} (61.6 - 40.6) = 8.28 \text{ IN}^4$

$I_o = 8.28 - 1.70^{-2} \times 2.31 = 1.66 \text{ IN}^4$

$I_{xx} = 2 \, (2.31 \times 1.95^2) + 2 \times 1.66 = 20.92 \text{ IN}^4$

$Q_{xx} = 2.31 \times 1.95 + (.250 \times .220 \times .125)2 = 4.53 \text{ IN}^3$

$I_{yy} = 2 \times 8.28 + 2(.50 \times .220 \times 2.74^2) = 18.21 \text{ IN}^4$

$Q_{yy} = 2.31 \times 1.70 + .500 \times .220 \times 2.74 = 4.23 \text{ IN}^3$

AREA $= .7854 \, (5.60^2 - 5.09^2) + 1 \times .220 = 4.55 \text{ IN}^2$

$C_x = 3.05$

$C_y = 2.85$ $\quad$ $\tan\beta = \frac{M_{yy} \, I_{xx}}{M_{xx} \, I_{yy}} = \frac{162000 \times 20.92}{1{,}260{,}000 \times 18.21} = .148$

$M_{xx} = 132860 \times 9\,1/2 = 1{,}260{,}000$ IN lb. $\quad$ $\beta = 8°20'$

$M_{yy} = 17065 \times 9\,1/2 = 162{,}000$ IN lb.

POINT "A" IS CRITICAL FOR UNSYMM. BENDING

X = .4 Y = 3.05 (CONSERV.)

NOTE COND $10a_{(2)}$ CRITICAL AT THIS SECTION.

Date

SECT F-F CONT'D.

POINT A

$$f_{bx} = \frac{1,260,000 \times 3.05}{20.92} = 184,000 \text{ psi}$$

$$f_{by} = \frac{162,000 \times .4}{18.21} = 3550 \text{ psi}$$

$$f_c = \frac{31800}{4.55} = 7000 \text{ psi}$$

$F_{bx} = 1.17 \times 170,000 = 199,000$ psi D/t $= \frac{6.10}{2.9} = 21$ REF PG 17

$F_{by} = 1.13 \times 170,000 = 192,000$ psi D/t $= \frac{5.70}{2.20} = 25.8$

$F_c = 170,000$ psi

$R_{bx} = .925$

$R_{by} = .0184$

$R_c = .041$

$$M.S. = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = .018$$

SHEAR (CRITICAL SECTION) OF TRUNNION

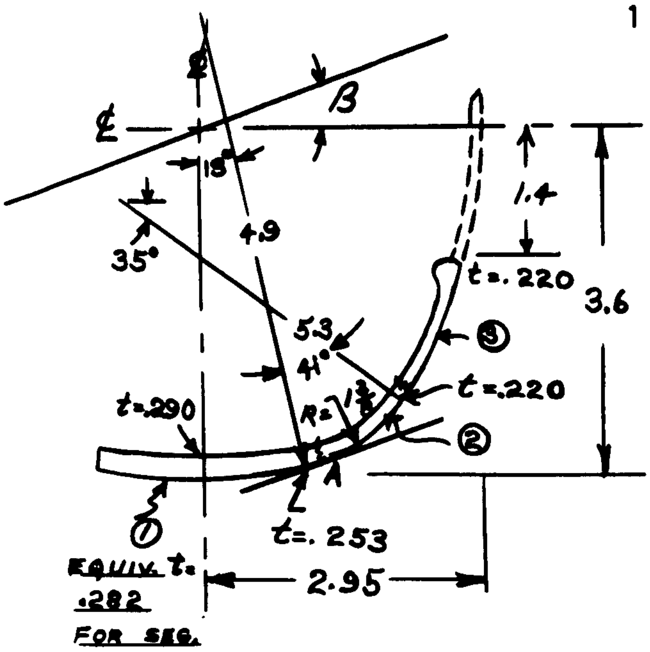
$$f_s = \frac{VQ}{Ib} = \frac{132860 \times 4.53}{20.92 \times 2 \times .220} = 65,200 \text{ psi}$$

$F_s = 100,000$ psi

USE 1.5 STRESS CONC. IN SHEAR

$$M.S. = \frac{100,000}{65,200 \times 1.5} - 1 = .02$$

Date 3-27-53



SCALE-HALF SIZE

SECT. E-E

1. CENTROIDS

SEG. (1) $\bar{y} = 3.60 - [R(1-\frac{\sin\alpha}{\alpha}) + t/2]$

$\bar{y} = \underline{3.42}$ $\alpha = 13^\circ$, R= 4.9, $t_{eq.} = \underline{.282}$

SEG. (2) $\bar{y} = h_1 + h_2/2$

$h_1 = \sin 35^\circ \times 5.3 = 3.03$

$h_2 = 3.6-(4.9-4.9\cos 13^\circ)$

$= 3.47$

$\bar{y} = \underline{3.25}$

SEG. (2) $\bar{X} = h_1 + h_2/2$

$h_1 = \sin 13^\circ \times 4.9 = 1.10$

$h_2 = 2.95-(5.3-5.3\cos 35^\circ)$

$= 1.97$

$\bar{X} = \underline{1.54}$

SEG. (3) SCALED

2. AREAS A= $(2\alpha Rt)$ t = thick (AVG.)

SEG (1) A = 2 x .227 x 4.9 x 282 = .631 IN^2 $\alpha = 13^\circ$ R= 4.9 (2.24)

(2) A = 2 x .3575 x 1.375 x .237 = .233 IN^2 α = 4 1/2= 20 1/2, R = 1.375 (.98)

(3) A = (5.3 x .608-1.4) x .220 = .398 IN^2 $\alpha = 35^\circ$ R=5.3 (1.81)

3. MOMENTS OF INERTIA (SECTIONS)

SEG (1) $I_{yy} = R^3 t(\alpha - \sin\alpha\cos\alpha)$

$= 4.9^3 \times .282 (.227 - .225 \times .973)$

$= \underline{.266\ IN^4}$

SEG (3) $I_{xx} = \frac{.220 \times 1.81^3}{12} = \underline{.1095}\ IN^4$ (FOR 1.81 DIM. SEE (3) AREAS)

Date 3-27-53

SECT. E-E CONT'D

4 MOMENTS OF INERTIA (TOTALS)

ITEM	NO.	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
(1)	2	.631	1.262	3.42	4.32	14.80	
(2)	4	.233	.932	3.25	3.03	9.85	
(3)	4	.398	1.592	2.305	3.68	8.47	.1095x4
			3.786		11.03	33.12	.438

$I_{xx} = 33.12 + .44 = \underline{33.56}$ IN^4

$Q_{xx} = \frac{11.03}{2} = \underline{5.51}$ IN^3

ACTUAL AREA ITEM (1) = 2 Rt = (2 x .227 x 4.9 x 2.72)2= 1.220
ITEM (1)&(2)&(3) = 1.220 + .932 + 1.592=$\underline{3.744}$ IN^2

ITEM	NO.	A SEC.	A (TOT.)	h	Ah	Ah^2	I_o
(1)	2	.631	1.262	---	---	---	.266x2
(2)	4	.233	.932	1.54	1.435	2.21	
(3)	4	.398	1.592	2.40	3.820	9.19	
			3.786		5.255	11.40	.532

$I_{yy} = 11.40 + .53 = \underline{11.93}$ IN^4

$Q_{yy} = \frac{5.255}{2} + .631 \times \frac{2.24}{4} = \underline{\underline{2.98}}$ IN^3 (FOR 2.24 SEE SEG (1) AREAS)

5. M_{xx} = 132860 x 11 1/2 = 1,530,000 "# (REF PG 1)

M_{yy} = 17065 x 11 1/2 = 196,000 "# CRIT COND. 10a (2)

$$TAN = \frac{M_{yy}\ I_{xx}}{M_{xx}\ I_{yy}} = \frac{196,000 \times 33.56}{1,530,000 \times 11.93} = .360$$

$$= 19^{\circ}\ 40'$$

POINT "A" IS CRITICAL FOR UNSYMM. BENDING
X- 1.25 Y- 3.38

6. POINT A

f_{bx} = 1,530,000 x 3.38/33.56 = 154000 psi

f_{by} = 196,000 x 1.25/11.93 = 20500 psi

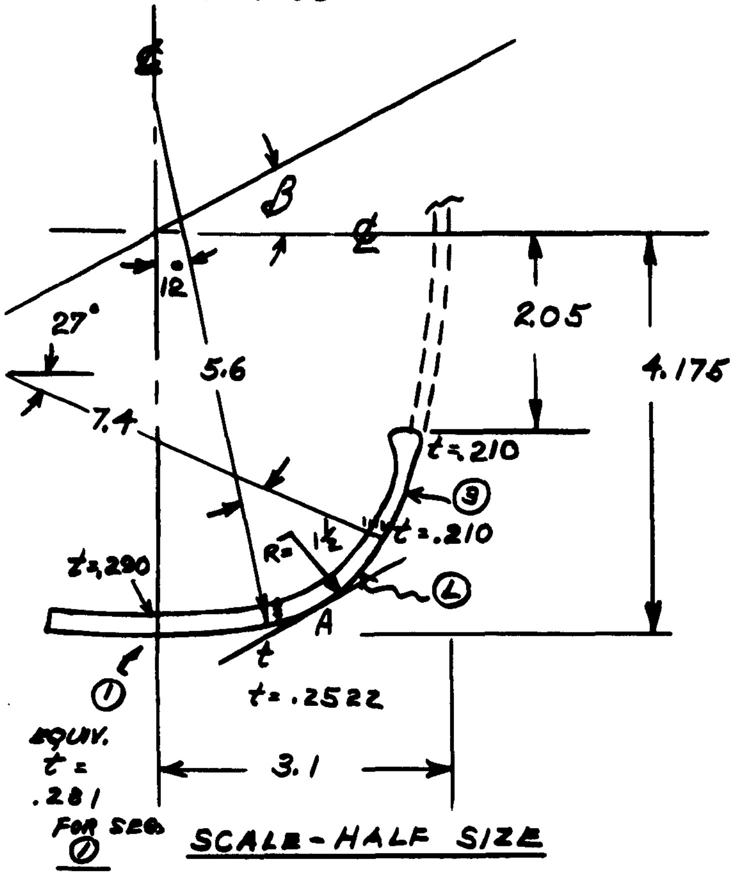
f_c = 31800/3.744 = 3490 psi

F_{bx} = 1.138 x 170,000 = 193,500 psi; F_{by} = 1.125 x 170,000 = 191,500 psi

F_c = 170,000 psi R_{bx} = .795 R_{by} = .107 R_c = .050

REF PG 17 (ALLOW.) $M.S. = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = \boxed{.05}$

Date 3-29-53



SECT. D-D

1. **CENTROIDS**

SEG.(1) $\bar{y} = 4.175 - \left[R - \left(1 - \frac{\sin\alpha}{\alpha}\right) + \frac{t}{2}\right]$

$\bar{y} = \underline{4.01}$ $\alpha = 12^\circ$, $R = 5.6$, $t_{eq.} = .281$

SEG.(2) $\bar{y} = h_1 + h_2/2$

$h_1 = \sin 27^\circ \times 7.4 = 3.37$

$h_2 = 4.175 - (5.6 - 5.6\cos 12^\circ) = 4.05$

$\bar{y} = \underline{3.71}$

SEG (2) $\bar{x} = h_1 + h_2/2$

$h_1 = \sin 12^\circ \times 5.6 = 1.16$

$h_2 = 3.1 - (7.4 - 7.4\cos 27^\circ) = 2.3$

$\bar{x} = \underline{1.73}$

SEG (3) SCALED

2. AREAS $A = (2\alpha R t)$ $t = \frac{\text{(AVG. THICK)}}{2.34}$

SEG. (1) $A = 2 \times .209 \times 5.6 \times .281 = .658$ $\alpha = 12^\circ$ $R = 5.6$

(2) $A = 2 \times .436^{1.31} \times 1.5 \times .231 = .303$ $\alpha = 5^\circ/2 = 25^\circ$ $R = 1.5$

(3) $A = (.470 \times \underset{1.44}{7.4} - 2.05) \times .210 = .303$ $\alpha = 27^\circ$ $R = 7.4$

3. **MOMENTS OF INERTIA** (SECTIONS)

SEG (1) $I_{yy} - R^3 t\,(\alpha - \sin\alpha\cos\alpha)$
$= 5.6^3 \times .281\ (.209 - .208 \times .978) = \underline{.248\ \text{IN}^4}$

SEG (3) $I_{xx} = \frac{.210 \times 1.44^3}{12} = \underline{.0520}\ \text{IN}^4$

Date 3-29-53

SECT. D-D CONT'D

4 MOMENTS OF INERTIA (TOTALS)

ITEM	NO	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
1	2	.658	1.316	4.01	5.27	21.2	
2	4	.303	1.212	3.71	4.50	16.7	
3	4	.303	1.212	2.77	3.37	9.4	.052 x 4
			3.740		13.14	47.3	.208

$I_{xx} = 47.3 + .21 = \underline{47.51}$ IN^4

$Q_{xx} = \dfrac{13.14}{2} = \underline{6.57}$ IN^3

ACTUAL AREA ITEM (1) = 2 Rt = (2 x .209 x 5.6 x .271)2 = 1.270 IN^2

ITEM (1)&(2)&(3) = 1.270 + 1.212 + 1.212 = $\underline{3.694}$ IN^2

ITEM	NO	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
1	2	.658	1.316	-----	----	-----	.248x2
2	4	.303	1.212	1.73	2.10	3.64	
3	4	.303	1.212	2.50	3.03	7.57	
			3.740		5.13	11.21	.496

$I_{yy} = 11.21 + .50 = \underline{11.71\ IN^4}$

$Q_{yy} = \dfrac{5.13}{2} + .658 \times \dfrac{2.34}{4} = \underline{2.96\ IN^3}$ (FOR 2.34 SEE SEG (1) AREAS)

5. M_{xx} = 132860 x 13 1/2 = 1,790,000 "# (REF. PG 1)

M_{yy} = 17065 x 13 1/2 = 230,000 "# CRIT. COND 10a (2)

$$TAN = \frac{M_{yy}\ I_{xx}}{M_{xx}\ I_{yy}} = \frac{230,000 \times 47.51}{1,790,000 \times 11.71} = .522$$

$= 27^\circ\ 30'$

POINT "A" IS CRITICAL FOR UNSYMM. BENDING.

X = 1.65 Y = 3.80

6. POINT "A"

f_{bx} = 1,790,000 x 3.80/47.51 = 143,000 psi

f_{by} = 230,000 x 1.65/11.71 = 32,400 psi

f_c = 31,800/3.694 = 8620 psi

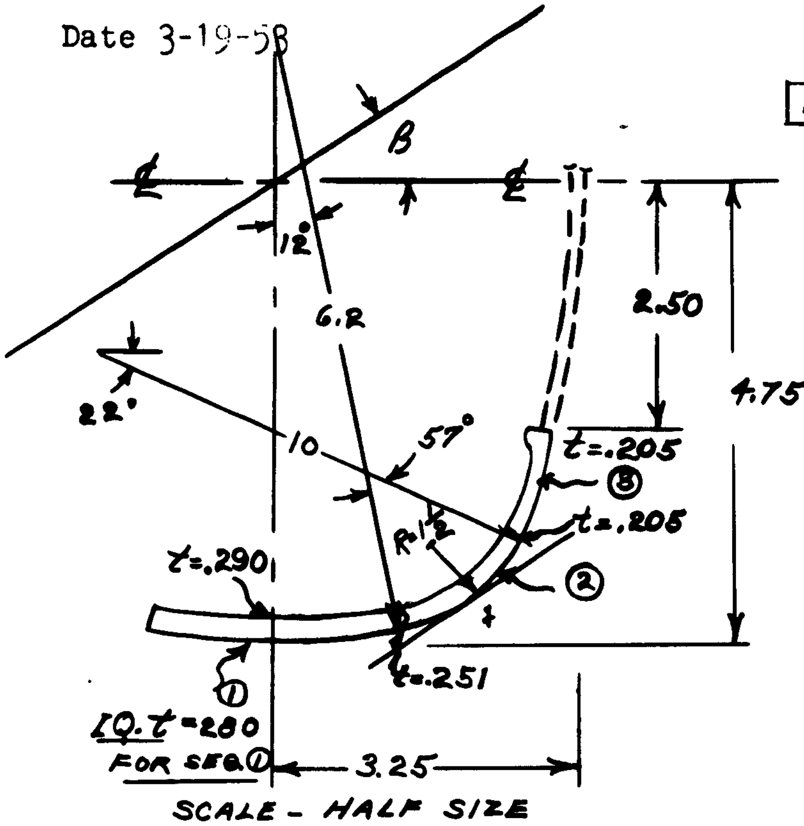
F_{bx} = 1.11 x 170,000 = 189000 psi; F_{by} = 1.10 x 170,000 = 188,000psi

F_c = 170,000 psi R_{bx} = .756 R_{by} = .172 R_c = .051

REF PG 17 ALLOW.

$$M.S. = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = .04$$

Date 3-19-58



SEC. C-C

1. CENTROIDS

SEG (1) $\bar{y}=4.75-\left[R\left(1-\overset{.031}{\frac{\sin\alpha}{\alpha}}\right)+t/2\right]$

$\bar{y}=4.58$ $\alpha=12^\circ$, $R=6.2$

$t_{eq.} = 2.80$

SEG (2) $\bar{y}= h_1 + h_2/2$

$h_1=\sin 22^\circ \times 10.0=3.75$

$h_2=4.75-(6.2-6.2\cos 12^\circ)$

$= 4.61$

$\bar{y} = \underline{4.18}$

SEG (2) $\bar{x} = h_1 + h_2/2$

$h_1 = \sin 12^\circ\ 6.2=1.29$

$h_2=3.25-(10-10\cos 22^\circ)$

$= 2.52$

$\bar{x} = \underline{1.90}$

SEG (3) SCALED

2. AREAS $A = (2\alpha Rt)$ (t=AVG EQUIV THICK)

SEG (1) $A=2 \times .209 \times \overset{2.59}{6.2} \times .280 = .272\ IN^2$ $=12^\circ$ $R=6.2$

(2) $A=2 \times .4975 \times 1.495 \times .228 = .340\ IN^2$ $=3\ 7/2=28\ 1/2^\circ$ $R=1.5$

(3) $A=(\underset{1.33}{.383 \times 10.0-2.50}) \times .200 = .273 IN^2$ $= 22^\circ$, $R=10.0$

3. MOMENT OF INERTIAS (SECTIONS)

SEG (1) $I_{yy} = R^3t(\alpha - \sin\alpha\cos\alpha)$
$= 6.2^3 \times .280\ (.209-.208 \times .978)$
$= \underline{.332}\ IN^4$

SEG (3) $I_{xx} = .205 \times \frac{1.33^3}{12} = \underline{.0403}\ IN^4$

Date 3-30-53

SEC C-C CONT'D

4. MOMENTS OF INERTIA (TOTAL)

ITEM	NO	A SEC	A TOT	h	Ah	Ah^2	I_o
1	2	.727	1.454	4.58	6.66	30.60	
2	4	.340	1.360	4.18	5.70	23.80	
3	4	.273	1.092	3.17	3.46	11.00	.0403x.4
			3.906		15.82	65.40	.16

I_{xx} = 65.40 + .16 = $\underline{65.56}$ IN^4
Q_{xx} = 15.82 /2= $\underline{7.91}$ IN^3

ACTUAL AREA ITEM (1) = (2 Rt) = (2 x .209 x 6.2 x .270)2 = 1.40

ITEM (1)&(2)&(3) = 1.40 + 1.36 + 1.092 = $\underline{3.85}$ IN^2

ITEM	NO	A SEC	A TOT	h	Ah	Ah^2	I_o
1	2	.727	1.454	----	------	--- -	.332 x 2
2	4	.340	1.360	1.90	2.58	4.91	
3	4	.273	1.092	2.65	2.90	7.70	
			3.906		5.48	12.61	.664

I_{yy} = 12.61 + .66 = $\underline{13.27}$ IN^4
Q_{yy} = 5.48/2 + .727 x $\frac{2.59}{4}$ = $\underline{3.21}$ IN^3 (FOR 2.59 SEE SEC. (1) AREAS)

5. M_{xx} = 132860 x 15 1/2 = 2,058,000 IN lb (REF PG1)

M_{yy} = 17065 x 15 1/2 = 264,000 IN lb CRIT COND 10a(2)

$$TAN \ \frac{M_{yy}I_{xx}}{M_{xx}I_{yy}} = \frac{264,000 \times 6556}{2,058,000 \times 13.27} = .635 \qquad 32^\circ\ 30'$$

POINT "A" IS CRITICAL FOR UNSYMM. BENDING
POINT A X = 1.95 Y = 4.36

6. POINT "A"

f_{bx} = 2,058,000 x 4.36/65.56 = 136,500 psi
f_{by} = 264,000 x 1.95/13.27 = 38,800 psi
f_c = 31800/3.85 = 8250 psi

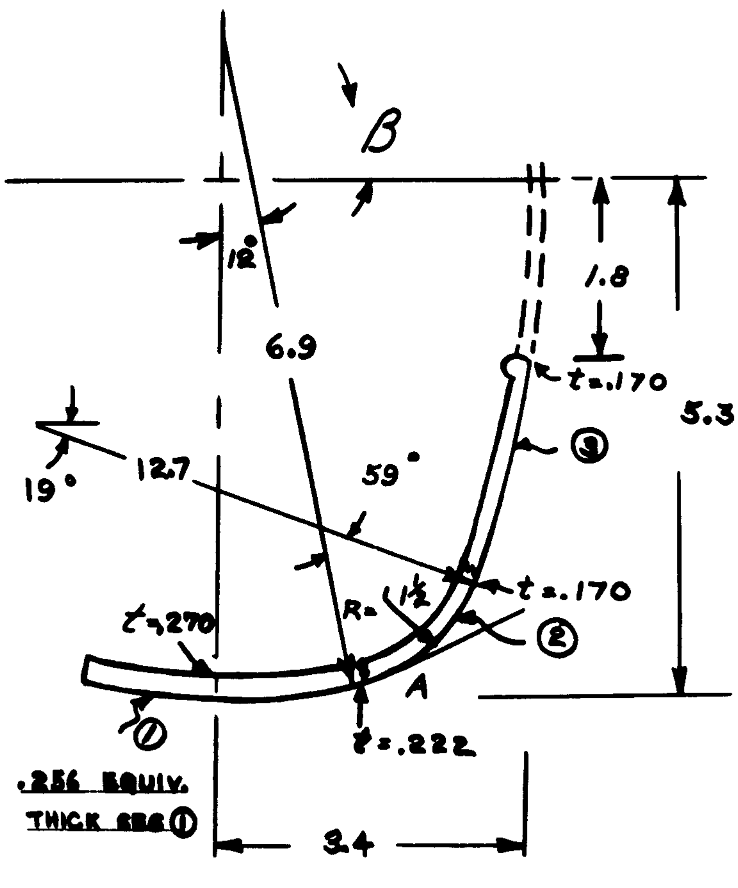
F_{bx} = 185,000 psi, F_{by} = 186,000 psi F_c = 170,000 psi

R_{bx} = .737, R_{by} = .208, R_c = .048

REF PG17 ALLOW.

$$M.S. = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = \underline{.005}$$

Date 3-29-53



SEC. B-B

1. **CENTROIDS**

SEG (1) $\bar{y} = 5.3 - \left[R\left(1 - \overset{.0345}{\frac{\sin\alpha}{\alpha}}\right) + t/2\right]$

$\bar{y} = \underline{5.14}$ $\alpha = 12^\circ$, $R = 6.9$, $t_{eq} = \underline{.256}$

SEG (2) $\bar{y} = h_1 + h_2/2$

$h_1 = \sin 19^\circ \times 12.7 = 4.13$

$h_2 = 5.3 - (6.9 - 6.9\cos 12^\circ) = 5.15$

$\bar{y} = \underline{4.64}$

SEG (2) $\bar{x} = h_1 + h_2/2$

$h_1 = \sin 12^\circ\, 6.9 = 1.43$

$h_2 = 3.4 - (12.7 - 12.7\cos 19^\circ) = 2.70$

$\bar{x} = \underline{2.06}$

SEG (3) SCALED

2. **AREAS** $A = 2(\alpha R t)$

SEG (1) $2 \times .209 \overset{2.88}{\times} 6.9 \times .256 = .738 \text{ IN}^2$ $\alpha = 12^\circ$ $R = 6.9$

SEG (2) $2 \times .515 \overset{1.55}{\times} 1.5 \times .196 = .304 \text{ IN}^2$ $\alpha = \frac{59}{2} = 29\ 1/2^\circ$ $R = 1.5$

SEG. (3) $(.331 \times \underset{2.4}{12.7 - 1.8}) \times .170 = .408 \text{ IN}^2$ $\alpha = 19^\circ$ $R = 12.7$

3. **MOMENTS OF INERTIA** (SECTIONS)

SEG (1) $I_{yy} = R^3 t\,(\alpha - \sin\alpha\cos\alpha)$

$= 6.9^3 \times .256\,(.209 - .208 \times .978)$

$= \underline{.4201} \text{ IN}^4$

SEG (3) $I_{xx} = \dfrac{.170 \times 2.4^3}{12} = \underline{.196} \text{ IN}^4$

Date 3-30-53

SEC B-B CONT'D

4. MOMENTS OF INERTIA (TOTAL)

ITEM	NO	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
1	2	.738	1.476	5.14	7.60	39.20	
2	4	.304	1.216	4.64	5.64	26.20	
3	4	.408	1.632	3.00	4.90	14.70	.196x 4
			4.324		18.14	80.10	.784

$I_{xx} = 80.10 + .78 = \underline{80.88}\ IN^4$
$Q_{xx} = 18.14/2 = \underline{9.07}\ IN^3$

ACTUAL AREA ITEM (1) = 2 Rt = $(2 \times .209 \times 6.9 \times 2.46)2 = 1.416\ IN^2$

ITEM (1)+(2)+(3) = 1.416 + 12.16 + 1.632 = $\underline{4.264}\ IN^2$

ITEM	NO	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
1	2	.738	1.476	-----	-----	-----	.420x.2
2	4	.304	1.216	2.06	2.50	5.15	
3	4	.408	1.632	2.90	4.74	13.70	
			4.324		7.24	18.85	.84

$I_{yy} = 18.85 + .84 = \underline{19.69}\ IN^4$

$Q_{yy} = 7.24/2 + .738 \times \frac{2.88}{4} = \underline{4.15}\ IN^3$ (FOR 2.88 SEE SEC. (1) AREAS)

5. $M_{xx} = 132860 \times 17\ 1/2 = 2,330,000$ IN lb (REF PG1)

$M_{yy} - 17065 \times 17\ 1/2 = 298,000$ IN lb. CRIT. COND 10a (2)

$$TAN = \frac{M_{yy} I_{xx}}{M_{xx} I_{yy}} = \frac{298,000 \times 80.88}{2,330,000 \times 19.69} = .526$$
$$= 27^\circ\ 40'$$

POINT "A" IS CRITICAL FOR UNSYMM. BENDING

X - 1.62 Y - 4.95

6. POINT "A"

$f_{bx} - 2,330,000 \times 4.95/80.88 = 143,000$ psi

$f_{by} - 298,000 \times 1.62/19.69 = 24,600$ psi

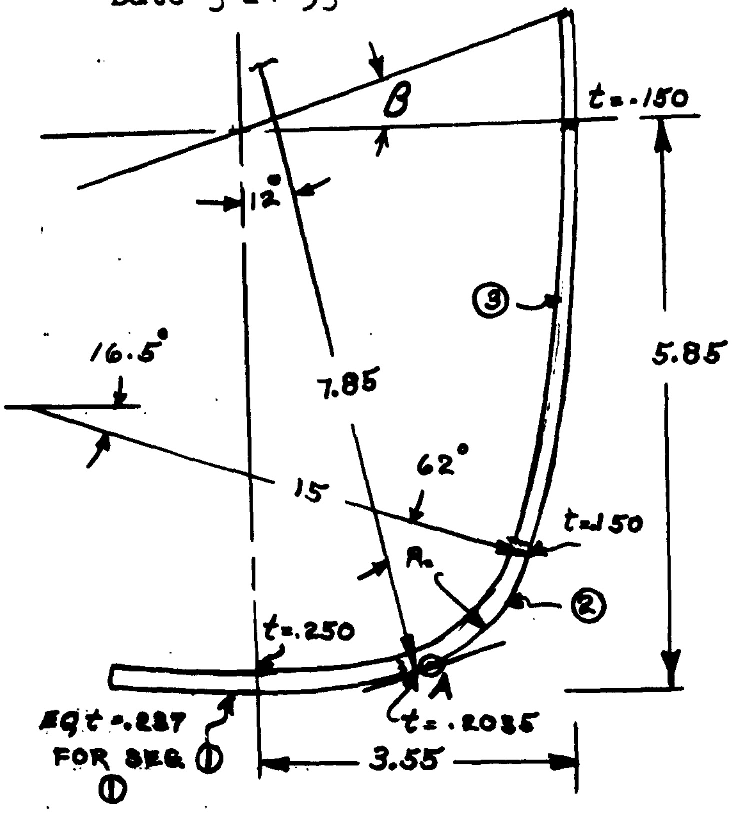
$f_c = 31800/4.264 = 7480$ psi

F_{bx} - 179000 psi, F_{by} = 178,500 psi, F_c = 170,000 psi
R_{bx} = .798 R_{by} - .1375 R_c = .044

REF PG17ALLOW

$$M.S. = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = \underline{.02}$$

Date 3-24-53



SECT. A-A

1. CENTROIDS

SEG (1) $\bar{y} = 5.85 - \left[R\left(1-\frac{\sin\alpha}{\alpha}\right) + t/2\right]$

$= 5.69$ $\alpha = 12^\circ$, $t = .250$,

$R = 7.85$

SEG (2) $\bar{y} = h_1 + h_2/2$

$h_1 = \sin 16.5^\circ \times 15 = 4.28$

$h_2 = 5.85 - (7.85 - 7.85\cos 12^\circ)$

$= 5.67$

$\bar{y} = 4.975$

SEG (2) $\bar{x} = h_1 + h_2/2$

$h_1 = \sin 12^\circ \times 7.85 = 1.63$

$h_2 = 3.55 - (15 - 15\cos 16.5^\circ)$

$= 2.95$

$\bar{x} = 2.29$

SEG (3) SCALED

2. AREAS $A = (2\alpha R t)$ WHERE t= AVG.

SEG. (1) = $A = 2 \times .2094^{(3.30)} \times 7.85 \times .237 = .775\ IN^2$ $(\alpha = 12^\circ)$

SEG. (2) $A = 2 \times 1.75 \times .541 \times .177 = .334\ IN^2$ $(\alpha = 6\ 2/2 = 31^\circ)$

SEG. (3) $A = 2 \times .288^{(8 \times 64)}\ 15 \times .150 = 1.300\ IN^2$ $(\alpha = 16.5^\circ)$

3. MOMENTS OF INERTIA (SECTIONS)

SEG. (1) $I_{yy} = \left[R^3 t\,(\alpha - \sin\ \cos\alpha)\right]$ $\alpha = 12^\circ$

$= 7.85^3 \times .237\ (.209 - .978 \times .208)$

$= .575\ IN^4$

SEG (3) $I_{xx} = \left[R^3 t\,(\alpha - \sin\alpha \cos\alpha)\right]$ $\alpha = 16.5^\circ$

$= 15^3 \times .150\ (.288 - .284 \times .959)$

$= .810\ IN^4$

Date 3-24-53

SECT. A-A CONT'D

4. MOMENT OF INERTIA (TOTALS)

ITEM	NO.	A SEC.	A TOT.	h	Ah	Ah^2	I_o
1	2	.775	1.550	5.69	8.80	50.0	
2	4	.334	1.336	4.975	6.65	33.0	
3	2	1.300	2.600	---	----	-----	8.10x2
TOTAL			5.486		15.45	83.0	16.20

$I_{xx} = 83.0 + 16.20 = \underline{99.2}$ IN^4

$Q_{xx} = \frac{15.45}{2} + 1.30 \times \frac{8.64}{4} = \underline{10.53}$ IN^3 (FOR 8.64 SEE SEG (3) UNDER AREAS)

ITEM	NO.	A SEC.	A (TOT)	h	Ah	Ah^2	I_o
1	2	.775	1.550	---	---	---	.575x2
2	4	.334	1.336	2.29	3.06	7.00	
3	2	1.300	2.600	3.28	8.52	27.90	
TOTAL			5.420		11.58	34.90	1.15

$I_{yy} = 34.90 + 1.15 = \underline{36.05}$ IN^4

$Q_{yy} = \frac{11.58}{2} + .775 \times \frac{3.30}{4} = \underline{6.43}$ IN^3 (FOR 3.30 SEE SEG.1)

5. $M_{xx} = 132860 \times 19\ 1/2 = 2{,}590{,}000$ IN lb.

$M_{yy} = 17065 \times 19\ 1/2 = 333{,}000$ IN lb.

COND $10a_{(2)}$ CRIT.

(PG 1)

$$\text{Tan}\,\beta = \frac{M_{yy} I_{xx}}{M_{xx} I_{yy}} = \frac{333{,}000 \times 99.2}{2{,}590{,}000 \times 36.05} = .354 \quad \beta = 19^\circ\ 30'$$

POINT "A" IS CRITICAL FOR UNSYMM. BENDING

$X = 1.95 \qquad Y = 5.65$

ACTUAL AREA = ITEM (1) $2 \times .2094 \times 7.85 \times .227 = .742$ OR

$2 \times .742 = 1.484$

ITEM (1)+(2)+(3)= $1.484 + 1.336 + 2.600 = \underline{5.42}$ IN^2

Date 3-24-53

SECT. A-A CONT'D

6. POINT A

$$f_{bx} = \frac{2{,}590{,}000 \times 5.65}{99.2} = 147{,}000 \text{ psi}$$

$$f_{by} = \frac{333{,}000 \times 1.95}{36.05} = 18{,}000 \text{ psi}$$

$$f_c = \frac{31800}{5.42} = 5870 \text{ psi}$$

$F_{bx} = 1.022 \times 170{,}000 = 174{,}500$ psi D/t $= \frac{11.70}{.250} = 46.8$

$F_{by} = 1.02 \times 170{,}000 = 174{,}000$ psi D/t $= \frac{7.10}{.150} = 47.2$

(REF PG 17 FOR ALLOW.)

$F_c = 170{,}000$ psi

$R_{bx} = .842$ $R_{by} = .103$

$R_c = .034$

$$\text{M.S.} = \frac{1}{R_{bx}+R_{by}+R_c} - 1 = .02$$

F_b BENDING ALLOWABLE STRESSES

SECTION		A-A	B-B	C-C	D-D	E-E	F-F	G-G
PAGE		15	13	11	9	7	4	3
Q_{xx}	(1)	10.53	9.07	7.9	6.57	5.51	4.53	3.92
I_{xx}	(2)	99.20	80.88	65.56	47.51	33.56	20.92	15.70
C_x	(3)	5.85	5.30	4.75	4.175	3.6	3.05	2.75
I_x/C_x	(4)	16.95	15.25	13.80	11.40	9.3	6.85	5.71
$R_x=2(1)/(4)$	(5)	1.245	1.19	1.145	1.155	1.185	1.32	1.37
F_{bx} *	(6)	210,000	201,000	194000	195000	200,000	222,000	230,000
Q_{yy}	(7)	6.43	4.15	3.21	2.96	2.98	4.23	SAME
I_{yy}	(8)	36.05	19.69	13.27	11.71	11.93	18.21	AS
C_y	(9)	3.55	3.40	3.25	3.10	2.95	2.85	ABOVE
I_y/C_y	(10)	10.15	5.80	4.07	3.78	4.04	6.38	
$k_y=2x(7)/(10)$	(11)	1.26	1.43	1.57	1.56	1.47	1.32	
F_{by}*	(12)	212000	240000	264000	262000	246000	222000	230000
D_x	(13)	11.70	10.60	9.50	8.35	7.20	6.10	5.50
t_x	(14)	.250	.270	.290	.290	.290	.290	.290
D_x/t_x	(15)	46.7	39.2	32.7	28.7	24.8	21.0	19.0
F_{bcx} (+)	(16)	174500	179000	185000	189000	193500	199000	206000
D_y	(17)	7.10	6.80	6.50	6.20	5.90	5.60	SAME
t_y	(18)	.150	.170	.205	.210	.220	.220	AS
D_y/t_y	(19)	47.2	39.8	31.7	29.5	26.8	25.4	ABOVE
F_{bcy}	(20)	174000	178500	186000	188000	191500	192000	206000

* $F_{bu} = f_{tu}$ 1t.961 (k-1) PG 146 JOUR. AER. SCI. MAY 1943

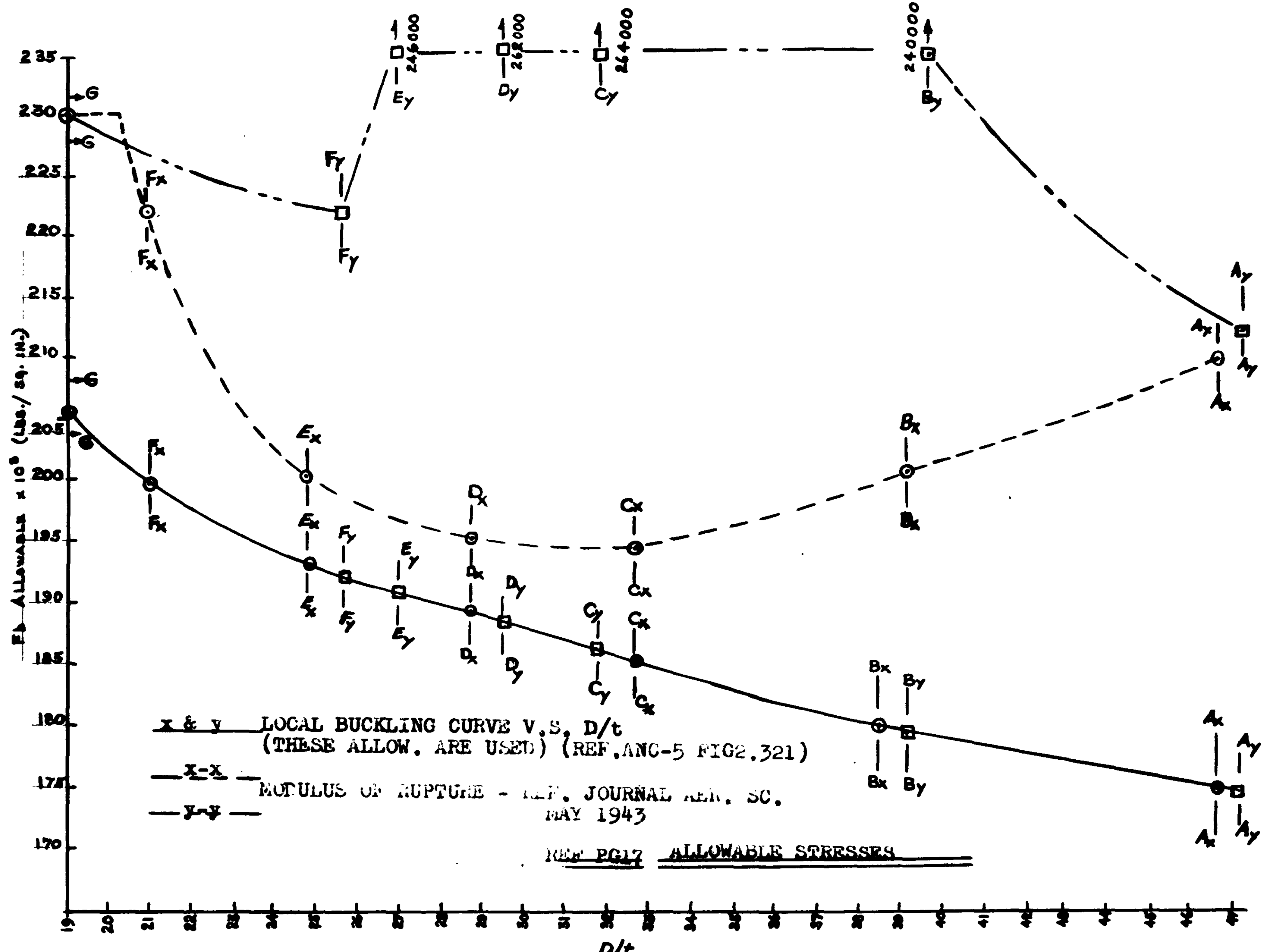
4330xxx-STEEL CASTINGS

$f_o/f_{tu} = .961$

$f_{tu} = 170,000$

(+) ANC-5 FIG 2.321

Date 3'30-53

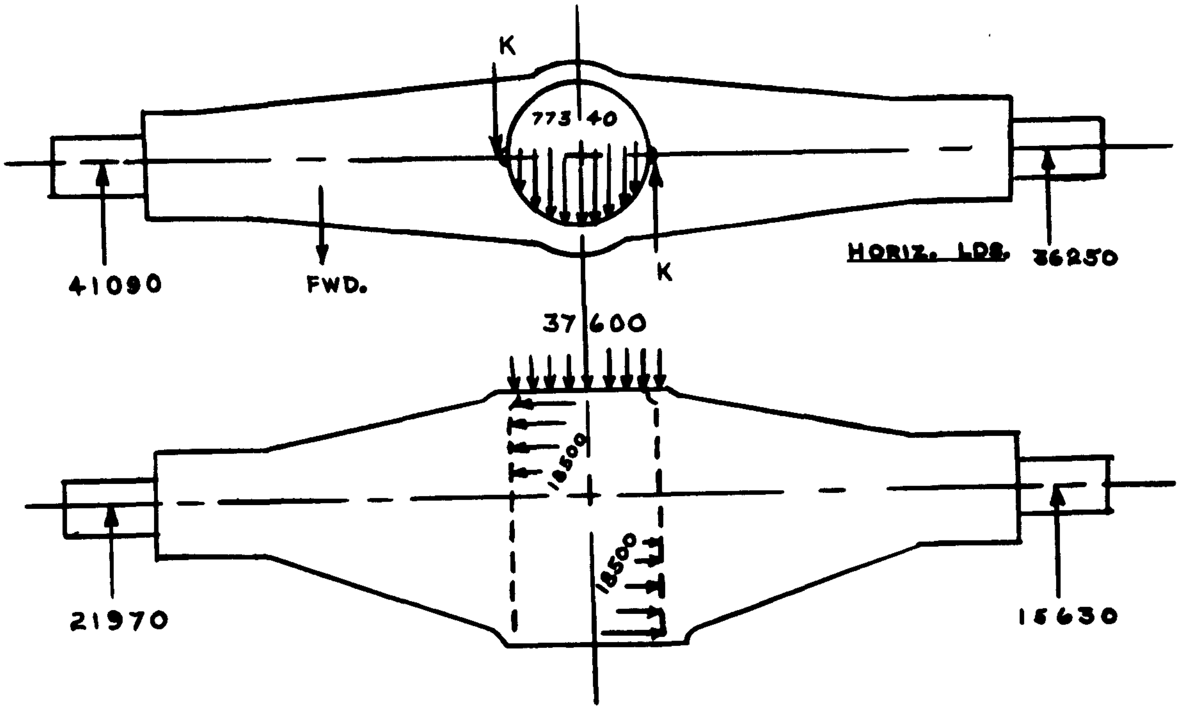


235
230
225
220
215
210
205
200
195
190
185
180
175
170
F_b Allowable x 10^3 (LBS./SQ. IN.)
D/t
246000
262000
264000
240000
G
F_x
F_y
E_x
E_y
D_x
D_y
C_x
C_y
B_x
B_y
A_x
A_y
x & y LOCAL BUCKLING CURVE V.S. D/t
(THESE ALLOW. ARE USED) (REF.ANC-5 FIG2.321)
x-x MODULUS OF RUPTURE - REF. JOURNAL AER. SC.
MAY 1943
y-y
REF PG17 ALLOWABLE STRESSES

Date 3-30-53

SEC. H-H CONT'D.

COND 1a SEE PG 1



VERT. LOADS

KEY LOAD K $= \dfrac{(41090 - 36250)\ 24.5}{7.688} = 15430^{\#}$

BENDING IN HORIZ. PLANE IS CARRIED BY TENSION IN THE FORWARD FLANGES AND COMPRESSION ON THE STRUT AND AFT. FLANGES. ASSUME TRIANGULAR DISTRIBUTION OF COMPRESSION STRESS WITH A COMPRESSION LOAD 6.76 INCHES FROM TENSION LOAD (SEE PAGE 20). THE LOAD IS ALSO DISTRIBUTED TO THE UPPER & LOWER FLANGES INVERSELY AS THE DISTANCE FROM THE TRUNNION CENTERLINE.

$$M_{HORIZ.} = 36250\ (24.5) + 15430\ \left(\frac{7.688}{2}\right)$$

$$= 947{,}400''^{\#}$$

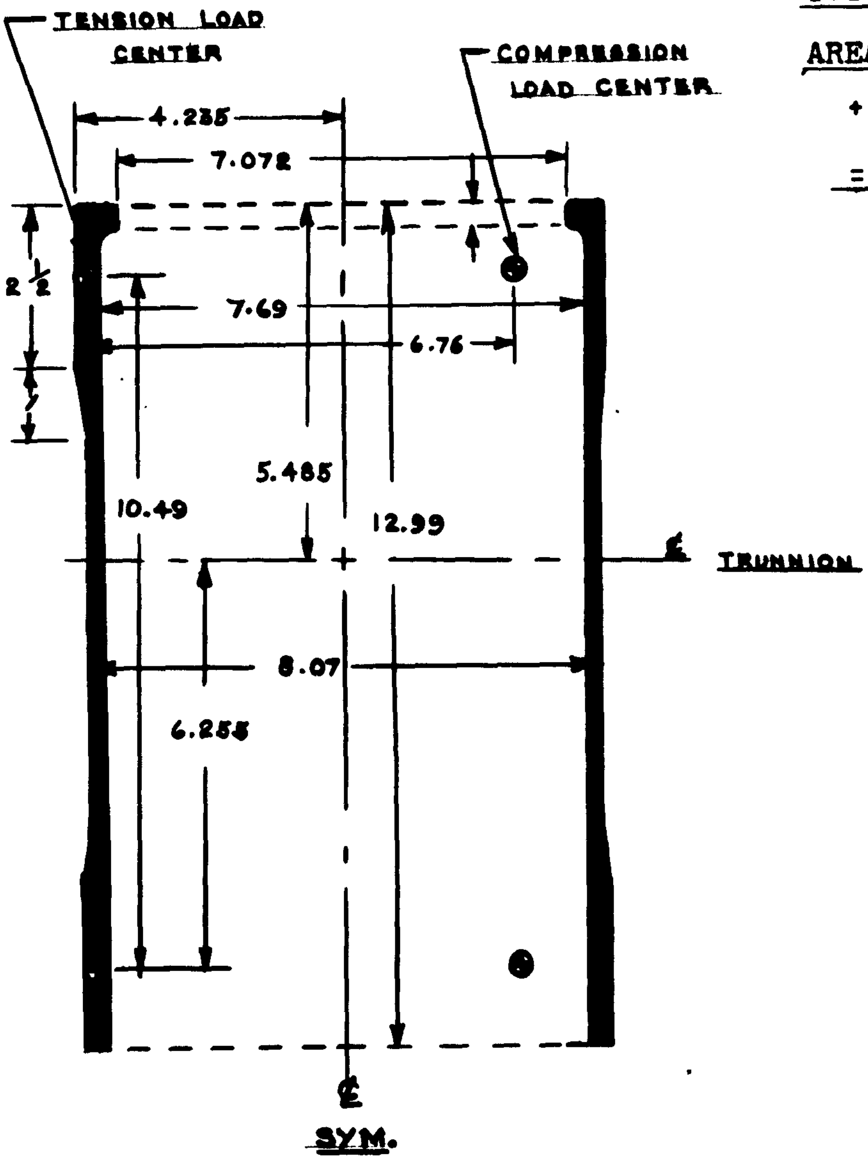
Date 3-30-53

SEC H-H AT

$A = (4.235 - 3.845)2.50 = \underline{.975} IN^2$

TOT. CROSS SECTION

$\underline{AREA} = (12.99-5.0)\ (8.07 - 7.69)$
$+ 4(.975) + (1 \times .1 \times 2)$
$= \underline{7.14\ In^2}$



Date 3-30-53

SEC H-H CONT'D

TENSION LOAD TO UPPER FORWARD FLANGE (HORIZ. BEND.)

$$= \frac{6.255}{10.49} \times \frac{947,400}{6.76} = 83,600\#$$

TENSION LOAD TO LOWER FORWARD FLANGE (HORIZ. BEND.)

$$= \frac{4.235}{10.49} \times \frac{947,400}{6.76} = 56700\#$$

BENDING IN VERTICAL PLANE IS CARRIED BY A COUPLE AT THE UPPER AND LOWER FLANGE LOAD CENTERS.

$$M_{VERT.} = \frac{37600}{2} (24.5-2.35) \qquad \text{(2.35 N.A. HALF CIRCLE)}$$

$$= 416,000''\#$$

TENSION LOAD TO LOWER FORWARD FLANGE (VERT. BEND.)

$$= \frac{416000}{2 \times 10.49} = 19800\#$$

EQUIVALENT COUPLE LOAD IN SOCKET

$$= \frac{21970-37600/2\ (24.5)}{1/3\ (12.99-.37)} = 18,500\#$$

TOTAL TENSION STRESS IN LOWER FORWARD FLANGE

$$f_t = \frac{56700 + 19800}{.975} + \frac{185.00}{7.14}$$

$$78400 + 25,900 = 104,300 \text{ psi}$$

SHEAR IN LOWER FORWARD FLANGE

$$f_s = \frac{(36250 - 15430)\ (4.235/10.49)}{.975}$$

$$= 21400 \text{ psi}$$

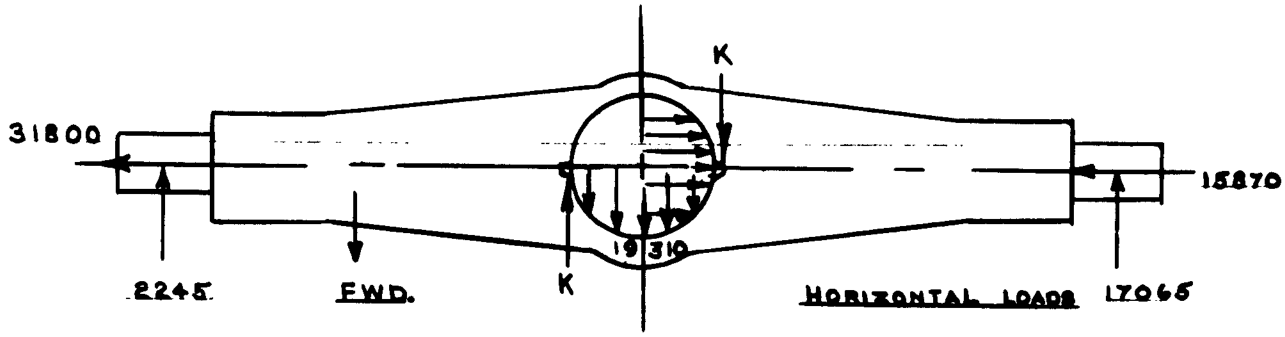
$$F_s = 100,000 \text{ psi}$$

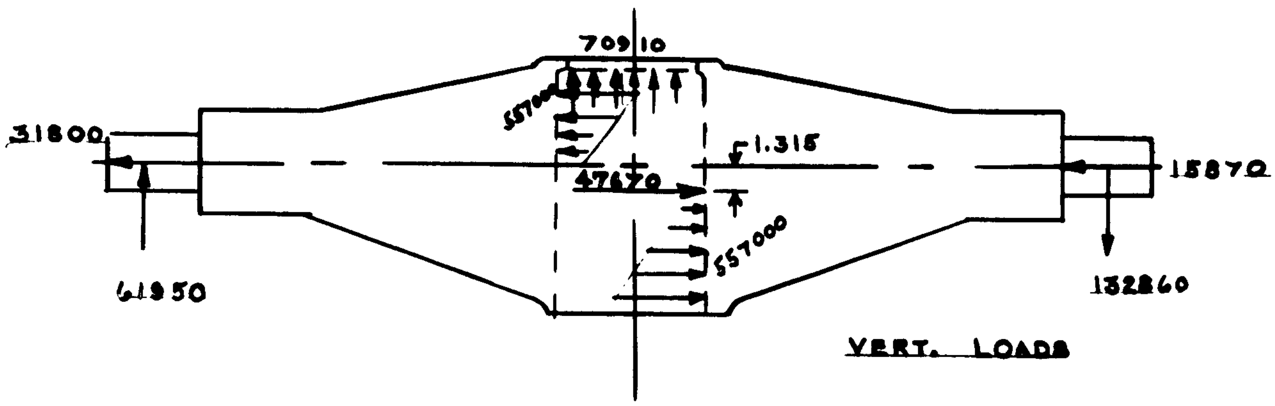
M.S. HIGH

Date 3-30-53

SEC H-H CONT'D

COND $10a_2$ (PG1)





$K = \frac{(17065 - 2245)\ 24.5}{7.688} = 47230\#$ SEE PG19 FOR METHOD

$M_{HORIZ} = 17065\ (24.5) - 47230\ (3.844)$
$= 236500\ ''\#$

TENSION LOAD TO UPPER FORWARD FLANGE (HORIZ. BEND.)

$$= \frac{6.255}{10.49} \times \frac{236500}{6.76} = 20900\#$$

EQUIVALENT COUPLE LOAD IN SOCKET

$$= \frac{(61950 + 70910/2)\ \ 24.5 - 31800\ (1.315)}{1/3\ (12.99 - .37)} = 557{,}000\#$$

SIDE LOAD IN SOCKET = 31800#

$M_{VERT} = \frac{70910}{2}\ (24.5 - 2.35)$

$= 785000\ ''\#$

TENSION LOAD TO UPPER FORWARD FLANGE (VERT. BEND.)

$$= \frac{785000}{2 \times 10.49} = 37400\ \#$$

Date 3-30-53

SEC H-H CONT'D

TOTAL TENSION STRESS IN UPPER FORWARD FLANGE

$$f_t = \frac{\frac{209000 + 37400}{.975} + }{59700} + \frac{\frac{557000 + 31800}{7.14}}{82,400} = 142,100 \text{ psi}$$

$$R_t = \frac{142100}{170,000} = .837$$

$$f_s = \frac{(2245 + 47230)}{.975} \; 6.255/10.49 + \frac{61950 + 70910/2}{7.14}$$

$$30200 + 13600 = 43800 \text{ psi}$$

$$R_s = \frac{43800}{100,000} = .438$$

$$M.S. = \frac{1}{\left[(.837)^2 + (.438)^2\right]^{1/2}} - 1 = \boxed{.055}$$

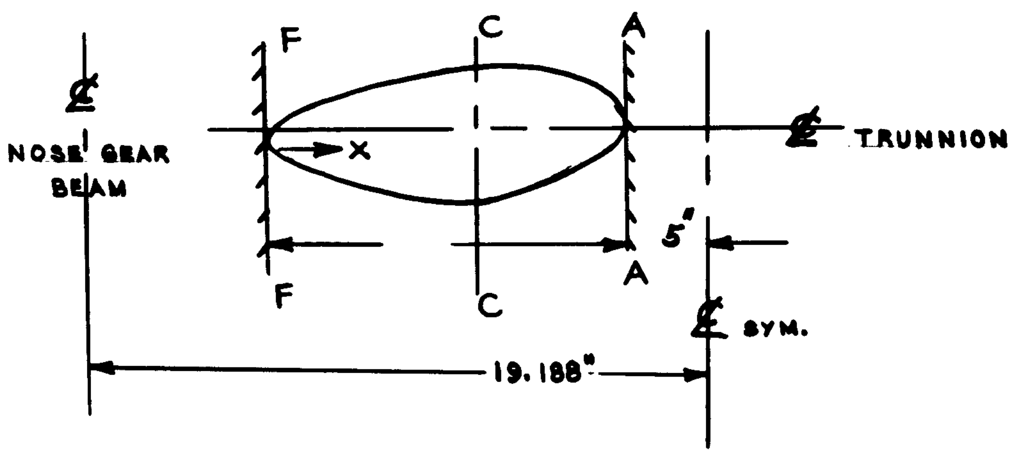
BEARING IN SOCKET
LIP OF TRUNNION COLLAR
BEARING FROM KEY

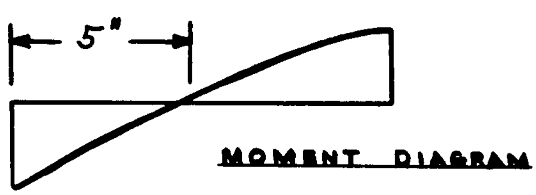
OK BY INSPECTION WITH ALUMINUM TRUNNION.

Date 4-1-53

RETRACTING LOADS

TORQUE IS PRODUCED ON THE R. H. S. BY THE RETRACTING CYLINDER. THIS TORQUE IS CARRIED AS DIFFERENTIAL BENDING BY THE UPPER AND LOWER CAPS IN THE VICINITY OF THE CUTOUT IN SIDE OF WEBS. AS SHOWN BELOW EACH END OF THE CUTOUT IS ASSUMED TO BE FIXED. THE POINT OF INFLECTION WILL BE TAKEN AT MID-LENGTH.





THE MAX. TORQUE FROM RETRACTING COND. (GEAR UP)
T- 47300 x 6.72 = 318000 "#

FLANGE SHEAR = T/h - 318000 /h

	X-0 (SEC. F-F)	X-5.0 (USE SEC C-C)
h	3.9*	8.0*
v	81,500#	39,700#

* DISTANCE BETWEEN CENTROIDS (PGS 4 & 10)

Date 4-1-53

RETRACTING LOADS CONT'D

MOMENT AT X=C (CRIT)

$$M_y = \frac{(81500 + 39700)}{2} \times 5 = 303,000 \text{ "\#}$$

$$f_{by} = \frac{MC}{I} = \frac{303,000 \times 2.85}{8.28} = 104,500 \text{ psi} \qquad C = 2.85 \quad I_{yy} = 8.28$$

$$F_{by} = 102,000 \text{ psi} \quad (\text{PG } 5) \qquad R_{by} = .544$$

REACTIONS AT NOSE GEAR BEAM

$$R_a = \frac{(19.188 + 24.5)}{49} 47300 = 42170\#$$

$$R_b = 5130\#$$

$$M_x = 5130 (24.5 + \overset{39.5}{\cancel{5.0}} + 10) = 203,000 \text{ "\#}$$

$$f_{bx} = \frac{MC}{I} = \frac{203,000 \times 3.05}{20.92} = 29,600 \text{ psi}$$

(PG 5)

$$F_{bx} = 199000 \text{ psi}$$

$$R_{bx} = .149$$

THE COMBINATION OF R_{by} & R_{bx} IS CONSERVATIVE SINCE THESE STRESSES DO NOT ACT ON THE SAME ELEMENT.

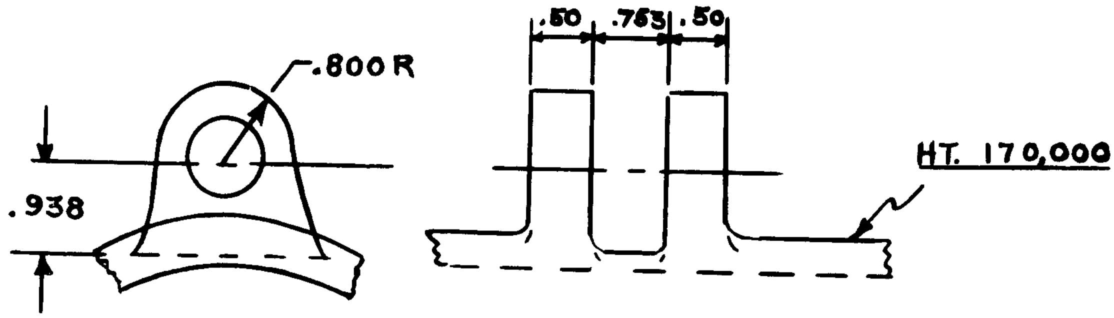
$$M.S. = \frac{1}{R_{bx} + R_{by}} - 1 = \boxed{.44}$$

Date 4-1-53

RETRACTING LOADS CONT'D.

LOADS FROM RETRACTING ARM CRITICAL WITH GEAR UP - RETRACTING COND.

$$47300 \times 6.2/5.1 = \underline{57500\#}$$



A SHEAR $= 4 \times .425 \times .500 = .850 \text{ IN}^2$

A TENS $= (1.6-.75)\ 2 \times .500 = .850 \text{ IN}^2$

A BEAR. $= 2 \times .75 \times .500 = .750 \text{ IN}^2$

$f_s = 57500/.85 = 67500$ psi $\qquad F_s = 100{,}000$ psi

$f_t = 57500/.85 = 67500$ psi $\qquad F_t = 170{,}000$ psi

$f_{br} = 57500/.75 = 76500$ psi $\qquad F_{br} = 196000$ psi

2 = BEARING FACTOR

$$\text{M. S.} = \frac{196000}{76500 \times 2} - 1 = \boxed{.27}$$

Date

WEIGHT STUDY

SECTION	AREA	MAIN BODY (PG1)		(STEEL)
G-G	4.80 SQ.IN.	6 x 4.800 x 2	=	57.50
F-F	4.55	1 1/2 x 4.675 x 2	=	14.05
E-E	3.744	2 x 4.147 x 2	=	16.55
D-D	3.69	2 x 3.717 x 2	=	14.85
C-C	3.85	2 x 3.77 x 2	=	15.10
B-B	4.26	2 x 4.05 x 2	=	16.20
A-A	5.42	2 x 4.84 x 2	=	19.38
		1 1/2 x 5.42 x2	=	16.30
				169.93 x .286= 48.6#

CENTER SECTION (PG20) (STEEL)

$.7854\ (8.47^2 - 7.69^2)\ 2 \times 2\ 1/2 = 49.50$

$.7854\ (8.07^2 - 7.69^2)\ \times 7.99 = 47.20$

FILLETS $1 \times .2/2 \times 2 \times 3.14 \times 8.07 = 5.07$

$101.77 \times .286 = 29.1\#$

SPACERS REF PG2 (ALUMINUM)

$.7854\ (3.50^{-2} - 3.00^{-2})\ 5.85 = 14.90$

$.7854\ (4.92^{-2} - 3.50^{-2})\ 2.00 = 18.60$

33.50

2 SPACERS = 67.00 x .1 = 6.7#

ADDITIONAL FITTINGS (SEE DRAWING)

1.86 lbs USE = 2.0#

TOTAL WT. WITH SPACERS 86.4 lbs.

TOTAL WT. WITHOUT SPACERS 79.7 lbs.

SECTION IV - DOUGLAS C-124A NOSE LANDING GEAR TRUNNION

C. CONCLUSIONS: Relative to Producibility

Both Alternative Designs A and B reported are considered to be projected far beyond any comparable previous application of a high strength steel casting in aircraft or otherwise. They were designed from two different approaches, Alternative A specifically to:

1. Include maximum employment of design philosophy within the limitations dictated by interchangeability, form, section, weight, and material employed.

2. To meet strength-weight-form dictated and unavoidable cross-sectional gradation of materially varying thin sections.

While Design "A" attained maximum continuity of metal, it had distinct disadvantages in impedance to flow of coolant in heat treating.

Design Alternative A was designed for production by Contractor's proprietary process employing ceramic molds, centripetal casting, and integrated controls of metal temperature, rate of flow, and mold atmosphere. On review, Design A was considered to have a marginal probability of production by conventional process. A large Navy-owned centripetal casting machine, designed by Contractor on BuShips and BuAer projects, was planned for employment, and it was hoped that a compromise in experimentally producing castings in Contractor's commercial production Ni-Cr alloys, to provide form for stress evaluation, employing sand or "ceramisand" molds produced from wooden patterns, could be effected. This procedure admittedly held a low probability, but would have been attempted except for the fact that the casting machine was damaged by fire with no possibility of repair within time limits of contract.

Design Alternative B was conceived as the best compromise possible within the above limitations for production from wooden patterns, in sand molds, of forms for stress evaluation employing Contractor's pressure casting techniques to the minimum extent that they are applicable to sand molds statically poured. A further important factor in design was to provide for improved heat and coolant flow in heat treating process, in final design, by determining castability of design with subject modifications in experimental effort prior to projected production of high integrity castings beyond this project.

Employment of metal patterns was not contemplated nor provided for in budget in this preliminary effort. It soon became apparent that the accuracy attainable and/or available in wooden patterns would contribute such sectional variations as to render the cast forms produced substantially useless for evaluation by stress testing.

Section IV - C (continued)

It was Contractor's considered judgment, concurred with by engineering specialists of AMC, that the benefit to be gained by experimenting with wooden patterns was negligible, and that the remaining budget and time allowance on the project would not justify such effort. With AMC approval, remaining funds were returned by Contractor to AMC.

In conclusion, it is considered that:

A. One or both of subject designs have a fifty per cent probability of production and heat treatment to ensure their acceptability as aircraft components with existing facilities, and

B. Such probability can be increased to probable certainty with substantial expenditure on patterns and rigging, and after experimental production of a considerable number of experimental castings by Contractor's process.

SECTION V

CONCLUSIONS and RECOMMENDATIONS

APPROACH TO CONCLUSIONS

The "token" design and production effort reported represents a portion of the total effort expended within the original Outline of Effort (prior to Change Order No. 4) and the related contributary effort of Contractor and associates, and of the Project Advisory Committee. Conclusions are broadly based on the sum of cumulative experience and technology available from AMC sponsored effort beginning February 19, 1951.

Integrated with and, logically and technically, inseparable from such effort in approaching objectives is:

1. Contractor's six years of effort on Navy (BuAer - BuShips) sponsored casting research and development,

2. Contractor's related and, in part, integrated casting process development privately, and in cooperation with Pullman-Standard Car Manufacturing Co., Caterpillar Tractor Company, and others,

3. General Alloys Company's extensive casting design-process engineering and R&D, which preceeded above effort by twenty-nine years, and is variously integrated with same.

4. Contractor's current effort (in facilitation of advanced casting process designing and assembling extensively increased Navy and company owned facilities to extend Contractor's successful Navy sponsored R&D to sizable pilot production as a Navy Casting Process Facility, - BuAer Contracts in which Army Ordnance is participating).

Contractor knows of no fundamental principles, or of no pertinent factors in science, technology, or applied mechanics which can be soundly advanced to refute the conclusions presented. It is respectfully requested that Contractor be given the opportunity to defend the Conclusions and Recommendations herein presented, against any negative contention, in any company at any time and place.

- CONCLUSIONS -

1. <u>RE: CHASE AIRCRAFT COMPONENTS:</u>

   A. Results reported in Sections II and III indicate that steel and aluminum castings can, respectively, replace the steel and aluminum forgings currently employed as subject Chase landing gear components with benefit.

Section V (continued)

B. Substantial saving in weight, tooling and production cost is indicated.

C. Producibility with materially reduced facilities, as compared to forgings, is indicated.

D. High strength steel castings to replace subject forgings and similar forgings generally can, it is believed, be expediently projected to high production with advanced technology and process equipment.

E. Aluminum castings to replace forgings of subject component can probably be employed successfully.

F. Castings, as produced and tested, with greatly increased properties as compared to conventional aluminum castings, fall somewhat short of forging properties, the substitution being especially favored by design in this instance.

G. Where opportunity for process related design improvement exists, some substitution of castings produced by advanced process with reported physical properties is possible. Otherwise, direct substitution of castings for forgings must await needed and probably attainable improvement of materials supplied to foundries for melting, melting process, and other process factors and controls. Technology for such process improvement is available. Need and facilitation will determine its attainment.

2. RE: DOUGLAS AIRCRAFT COMPONENT:

A. The replacement of a high-strength aluminum forging employing highly developed material and forging techniques with a steel casting of equal strength-weight will be revolutionary in materials-process history if it can be successfully accomplished.

B. The probability of production of this specific configuration with existing facilities is considered to be approx. 50%.

C. Production is considered possible, through alteration of existing facilities and particularly the employment of specialized heat-treating facilities and specific "tooling".

D. The limitations imposed by the necessity of interchangeability with a component designed and produced by a radically different process require a form which imposes special problems, - not basically of casting the form, but of controlling form-related impedances and stresses in process, to insure acceptance in aircraft inspection.

E. It appears certain that many large landing gear components can be designed with full employment of casting design-process technology, and be successfully cast by advanced casting process, or highly controlled conventional process, to effectively replace forgings.

F. Conferences have been held by Contractor with a leading producer of landing gears which indicate that the process-inherent advantages of castings are recognized, and that advanced process castings, designed with full employment of casting design-process technology, will receive thorough consideration.

G. Producer states that defective castings, and lack of uniformity generally in commercial steel castings, has precluded his previous successful use of such castings.

H. Recommended effort for redesign, production, and testing of selected landing gear components is included in Recommendations.

3. RELATIVE TO STEEL CASTINGS:

A. That: a wide variety of High Integrity cast-steel aircraft, and missile components can be produced by advanced casting process in a far wider range of size and configuration than is possible by forging.

B. That: such castings can largely, and advantageously, replace steel forgings where forms scientifically designed for casting process can be employed.

C. That: Steel castings can replace a sizeable, as yet indeterminate, percentage of aluminum forgings and fabrication.

D. That: Steel casting potentials in strength-weight ratio, and economics, increase with size.

E. That: Steel castings will become mandatory as speeds, loads, and skin-temperatures increase.

F. That: the probability of producing large acceptable Titanium castings is, in time and technology, remote. Their properties currently unpredictable. No applicable facilities exist. Steel castings are "the bird in hand".

4. RELATIVE TO ALUMINUM CASTINGS:

A. That: aluminum castings can be produced by advanced casting process (currently in limited commercial production) with physical properties increased by 50% to 75% above "conventional" castings currently employed in aircraft. Such castings can replace a number, as yet indeterminate, of light metal forgings and fabrications.

Section V (continued)

B. __That__: the specialized proprietary processes currently producing superior castings have various limitations relating to sizes and, particularly, types of configurations producible.

C. __That__: existing U. S. casting technology can be expediently projected (with adequate facilitation) to produce aluminum castings of substantially unlimited size and configurations with properties reasonably approximating forgings.

D. __That__: even materially lower casting properties, in combination with inherently stronger forms non-forgeable, can produce components with strength-weight ratio favorably comparable to forgings.

E. __That__: the casting-process-inherent advantages of continuity and contour, and sectional gradation proportional to load, when fully employed in design, will produce components with superior strength-weight ratio to fabrications, despite "inferior properties" of the continuous casting as compared to local properties of the non-continuous assembly of "bits-pieces and rivets" (a "poor" casting will surpass a "perfect" fabrication in load capacity and "stiffeners" in many casting engineered applications).

F. __That__:

1. Commercial aluminum castings are, in general, grossly irregular in local properties, and predictable uniformities, as compared to "commercial" steel castings. (Sound steel castings do not vary appreciably in density as do aluminum castings.)

2. Principal cause is oxide contamination which disrupts continuity, creates "sponge" areas, increases permeability.

3. By supplying higher purity, non oxide-contaminated aluminum to foundries, removing exterior oxide accumulated in transit, and melting and casting under controlled atmospheres in non-organic molds, an incalculable increase in physical properties, uniformity and predictable reliability of aluminum castings, in aircraft and all defense materiel considered mandatory, can be attained. Pertinent technology is available and can be expediently applied by Contractor or other technically qualified organization with reasonable effort and facilitation, proportional to tonnage requirement.

4. Preoccupation with "miracle" metals is a psychological and budgetary diversion of needed and justifiable effort long overdue on cast materials and processes in volume production of defense materiel.

5. [redacted] __RELATIVE TO MAGNESIUM CASTINGS__:

A. __That__; magnesium castings are currently produced almost entirely by sand casting, employing mold materials and processes which ensure or permit gross contamination of the metal and result in castings materially inferior to aluminum castings in physical integrity, uniformity, and predictability.

B. That: the practice of employing highly porous magnesium castings and impregnating porous areas with synthetic resins, etc. is unjustifiable in the light of available technology.

C. That: magnesium castings can be materially improved in physical properties and, particularly, in density and predictable uniformity by competent and thoroughgoing application of known technology and advanced process.

D. That: material reduction of weight on aircraft engines can be achieved by such improvement of magnesium castings.

E. That: conventional die casting and permanent mold casting can and should be expediently applied in combination with simple atmosphere controls, and all possible magnesium castings be produced by such process where configurations permit the use of metal molds, and with ceramic molds and cores as specifically indicated by size and form.

6. [redacted] SHELL MOLDING:

(Note: The Croning German "shell" process was extensively investigated by Contractor on BuShips and BuAer Navy projects in 1947, and its development has been closely followed. Navy was a major factor in blocking attempts to obtain U. S. patents on the ground that Herr Croning had "invented" this process after the war, thus throwing the art wide open and bringing on an avalanche of promotional propaganda and some technical development. The major incentive to extension of this process is the rich reward to resin producers. Principal development has been in mechanization, of which Ford Motor is outstanding example.)

A. That: the shell molding process has all of the inherent disadvantages associated with employment of organic bonds in sand molds. In fact, the percentage of bond is materially increased, and the mold attains higher temperatures due to thin mass.

B. That: the process demands "hard metal patterns" with much higher surface finish (in order to draw off the tightly adhering, adhesively bonded shell mold), thus enforcing the necessity of craftsmanship and detail to beneficially upgrade patternmaking and attain better dimensional control in patterns generally.

C. That: there are many other mold materials, some, such as French sand, in use for foundries, that will produce superior finishes from the patterns employed in the shell process.

Section V (continued)

D. <u>That:</u> shell molding effects improvement in only one sector of the casting process and has some attending disadvantages, as well as manifest advantages, in many specific applications.

E. <u>That:</u>

1. Castings produced in shell molds do not approximate the dimensional control, finish, or metallurgical quality attainable in a variety of other mold materials.

2. Other processes, employing superior, non-organic bonded mold materials, include many other refinements of process contributing to the integrity of the casting, to producibility, and to overall economics.

F. <u>That:</u>

1. Shell molding unquestionably represents a material improvement in the finish and dimensional control, wherever it is employed in conventional sand foundries, which will benefit casting sales in some markets.

2. The economics of the process vary widely in specific applications.

3. The shell process is now a conglomeration of experimental equipment, resins, and techniques, much of which is superficial ingenuity and pseudo-technical. Foundry personnel employing such process have a minimum of educational and technical qualifications to evaluate the chemistry, physics and mechanics involved. From such intense experimental production and, particularly, promotional activity, some benefit will unquestionably emerge with the probability that a high percentage of such installations will be discarded.

4. Shell molds, in direct relation to the refinement of the patterns and related mechanics employed, can be beneficially employed in the production of a high percentage of low stressed, light metal castings currently employed on aircraft, and some small accessory steel castings.

G. <u>That:</u> at least one sand casting producer in the Los Angeles area is producing aluminum castings of nominal physical properties, with finish and dimensional control, in general, superior to the shell mold castings observed, as are others in other localities.

H. <u>That:</u> however acceptable the improvement effected by shell molding on any aircraft components, it must not be considered as contributing to improvement of physical properties, and should be employed only as an expedient until vastly superior U. S. process, now in commercial or pilot production, is expanded in facilitation to replace the inferior German process.

7. [redacted] RELATIVE TO "PRECISION" CASTINGS:

A. Due to a high degree of exploitation, the ambiguity of terminology, and lack of technical cognizance of producers and users, so-called precision, "investment" castings have received acceptance and employment in the aircraft industry to a far greater degree than in industry generally. While such processes admittedly "fill a gap", and have definite merit in the production of many items with "designed-in unpredictability" by other process, they are, in general, productive of the worst metal structures in point of grain size, orientation of structure, and predictable fatigue resistance, in existance.

B. That: basic shortcomings of such processes are:

1. The employment of hot molds which ensures abnormal growth of structure,

2. The employment of "toy" melting furnaces with unsuccessful temperature control, resulting in variations of temperature change, commonly produce a thousand per cent difference in grain size in such items as turbine blades, small rotors, etc., and lead to the practice of assembling parts with highly non-uniform and unpredictable fatigue life into critical limitations with resultant impairment of aircraft service and hazards to personnel.

C. That: the producibility and economics of such "investment" process, originally employed by the Chinese for jewelry and, later, effectively and economically employed to produce dental bridgework, impose limitations resulting in gross extravagance, as well as product inferiority, in application to any cast item which can be produced to meet rational service specifications realistically related to factual service requirements.

D. That: such investment processes are inherently inferior in dimensional control, as well as product physical properties, as compared to more direct and economic advanced casting process in limited commercial or pilot production.

E. That: great improvement in investment casting process, resulting in refined structures, and considered to be broadly applicable for material increase of properties and related fatigue life, has been effectively demonstrated in limited production, and can be broadly applied with simple technology and minimum facilitation.

F. That: Government specifications to control grain size should be applied to all investment castings employed in aircraft to upgrade such castings in physical properties and fatigue resistance.

G. That: the failure of investment gas turbine blades, to the extent that they have been eliminated from many engines, has been widely misinterpreted as indicative of the general inferiority of castings and the need for forgings on such applications.

H. That: not only turbine blades but turbine rotors with cast-in blades, and blades cast integrally with rotors, are producible with existing technology and minor alteration to existing facilities.

I. That: the greatly increased producibility and economic advantage of casting a great variety of gas turbine components in heat resistant and corrosion resistant alloys, in close approximation of finished form, and with the elimination of machining, welding, and assembly, wherever possible, unquestionably holds great promise.

J. That: the notching of flywheels (called turbine rotors) and the installation in such notches of wedges (called blades or buckets) is considered to hold disadvantages in service, producibility and economics, as compared to other production procedures which Contractor has recommended to military authorities since 1945, and will submit in detail on request.

8. RELATING TO REQUIREMENTS FOR PRECISION IN CASTINGS AND THEIR ATTAINMENT IN PROCESS:

A. That: the principal reasons justifying the expenditures in patterns and refinement of casting process to attain dimensional precision appear to be:

1. Reduction or elimination of machining and/or grinding.

2. Retention of the superior outer surface of castings.

3. The elimination of stresses and, particularly, dimensional change incident to machining.

4. The provision of surface to reduce or eliminate finishing.

B. That: the term "precision" has been very loosely applied in respect to castings (example: the plus or minus .05 per inch considered "precision" in investment castings could produce a one inch variation in 100 inches or about six times the acceptable tolerance in an as-cast tractor frame). Realistic consideration and related specifications are in order.

C. That: there is no point in controlling casting dimensions to provide less than 1/16" to 1/8" "finish" material on all surfaces which are machined by cutting tools as such "stock" is required to enable the tool to "bite" and hold into the cut and to provide for the dimensional variations in chucking and setup on machine tools.

Section V (continued)

D. That: excepting the preceding Conclusion, it is obvious that benefits of dimensional control on "finished surfaces" of castings must be approached alternatively as:

1. Produce a casting with a surface that requires no setup in machine tools and no finish which can not be applied with hand tools, beyond polishing, centerless grinding, etc., or

2. Produce a casting accurately cast, within five to fifteen thousandths of finished dimension, and remove necessary stock, to meet specifications, by grinding.

E. That:

1. Alternative "2" above is attainable in various degrees, on large and small castings, within limits of size and configuration.

2. Its justification is a matter of relative cost in relation to production quantity and to comparative machining and finishing costs by other means.

3. Large castings with very closely controlled overall dimensions are attainable, with suitable tooling, from advanced casting process.

4. The attainment of local dimensional control is much simpler. (Castings are currently produced in commercial process with one micro-inch finish and plus or minus .002 in twenty inches, in aluminum; have been produced to plus or minus .015 in ten feet in alloy steel.)

F. That:

1. It is, in general, more logical and economic to produce castings with dimensional control to eliminate machining with cutting tools and to permit final finish by grinding.

2. Castings produced in sand, plaster, and organic bonded molds have surface irregularities and porosity which require the removal of more surface stock than is practical by grinding.

3. Molds which do not react with metal must be employed to the exclusion of any organic bonded mold.

4. Atmosphere control in molds is essential in casting some metals and desirable in all metals.

G. That:

1. Grinding equipment to replace machining with cutting tools is rapidly increasing in use and is being steadily improved.

2. Grinding machines to finish castings by five to fifteen thousandths "stock" removal, providing the required form-related movements, employ far less power, require less rigidity and mass, and can be produced at a fraction of the cost of the machine tools they will replace.

3. As the stock removed by such tools is reduced by eighty-five to ninety-nine per cent, production rates will be greatly increased with a material reduction in labor, power, floor space, foundations, and transport.

4. The employment of such process will make great savings in the reduction of total metal weight in original castings and in elimination of machining scrap, "chips" and related contamination, melting loss and transport.

H. <u>That:</u>

1. Producing ceramic molds with five to fifteen thousandths tolerance, the entire process can be greatly simplified.

2. Such simplification will permit high volume production of ceramic molds and cores with a minimum of facilities, simple tooling, employing semi-skilled labor and extensively utilizing existing facilities.

3. Mold material required is a very small fraction of that required in other types of molds, and is 100% reuseable, largely eliminating handling facilities and transport.

4. Molds do not deteriorate in storage, can be stock-piled and transported as desired.

5. Ceramic molds are employed as "permanent" or expendable, depending upon metal cast and configuration of casting.

I. <u>That:</u>

1. A realistic and thoroughgoing evaluation to define needs and specifications for precision is long overdue.

2. Such evaluation must be jointly undertaken by casting process engineers, aircraft production specialists, and engineers of grinding machine and grinding materiel manufacturers.

9. <u>RE: DESIGN LATITUDE:</u>

A. <u>That:</u> design latitude of any process is a factor in U. S. air supremacy to the extent that it permits imaginative and effective employment of design intelligence and production of superior aircraft.

Section V (continued)

B. The design latitude permissible in fabricating airplanes from sheet metal bits and pieces, changeable at will, and employing a minimum of in-plant facilities, is unquestioned.

C. That: time is running out on fabricating aircraft from sheet metal by conventional process because:

1. Loads and speeds necessitate thicker, heavier metal sections, greater stresses, and a far higher degree of design technology.

2. The reduction of section, airfoil sections, and related fastening problems reduce possible application of historic fabricating techniques.

D. That:

1. Strength requirements necessitated the expedient employment of processes and materials at hand.

2. Expedients were enforced in a minimum of time and with less than full evaluation or utilization of existing and potential U. S. materials, processes, and applicable technical knowledge.

E. That: the design limitation imposed by available and projected forgings is currently unacceptable to many aircraft designers as is the extensive required machining and overall economics applicable if and when such large forgings are produced and employed.

F. That: the "hogging" of aircraft components from billets and slabs has vastly more latitude than forging with compromises in design, material strength, producibility, and economics.

G. That:

1. The aircraft industry must mandatorily employ far heavier equipment and processes extraneous to their operations and experience.

2. A minimum of existing industrial experience, processes and facilities have been applicable to the production of the configurations required.

3. Hurried development of equipment, with the normally expected shortcomings of process and product, has resulted.

H. That: when and if casting potentials are thoroughly investigated and evaluated, with specialists in advanced casting process fully participating, it will be determined that casting process is uniquely and inherently applicable to aircraft and missile production.

Section V (continued)

I. <u>That</u>:

1. The prevalent assumption that casting process does not permit latitude in design change, or that it is not suited for relatively small quantity production, is largely erroneous.

2. By employing a very small part of the ingenuity demonstrated by the aircraft industry in adapting other processes to need, if applied to the casting process with full cooperation of advanced casting experience, the inherent flexibility of the casting process will be realized and employed.

J. <u>That</u>: it is far cheaper to make alterations on patterns from which castings can be produced,in a matter of minutes or hours, than to spend a far greater effort in alteration of even a small number of aircraft by conventional production procedure.

K. <u>That</u>: the unquestioned economy of machining a pattern to attain dimensional requirements on a finished casting, rather than multiple machining of individual castings, is as applicable to other work applicable to other work applied to patterns and thus eliminated or reduced in subsequent process.

10. <u>FACILITATION OF CASTING PROCESS</u>:

(<u>Note</u>: the term "advanced casting process" is used to broadly include all of the known advances in casting process which are in commercial production, in pilot production, and soundly projected from pilot production. The term "casting process" in general use has been employed to denote all manner of minor improvements and/or complications of process components, such as: (1) patterns employed, (2) molding techniques, (3) melting and pouring techniques, (4) pressure casting by the ancient centrifugal and more modern uniform pressure techniques, (5) multiple casting, (6) atmosphere and temperature controls, etc.)

Contractor contends that all known and beneficially applicable casting techniques should be fully integrated and applied, with all applicable controls,and fully facilitated for the production of aircraft components and other defense materiel. Degree of applicability to different metals and product requirements and results produced should be fully evaluated by a thorough testing, accepted on the basis of merit, and the resultant products covered by realistic specifications, ensuring their acceptance and function as aircraft components.

The proprietary process of Contractor and associates, and processes developed in whole or in part on Contractor's Government-sponsored projects, receive no preferential consideration. Where other proprietary process, or any known process, is considered productive of, or contributary to, casting potentials in aircraft, knowledge of such process,with indicated improvement from some of available technology, has been a factor in Contractor's conclusions.

Section V (continued)

The term "high integrity castings", as employed, denotes castings of uniform and predictable metallurgical, physical, mechanical, and dimensional integrity which require employment of no "casting factors". Such castings are currently in limited commercial and pilot production, in specific materials, within limitations of size and form which can be expanded with requisite effort and facilitation, through the employment of available technology. Specifications for high integrity castings can only be developed after a substantial number of selected aircraft components have been produced by advanced casting process and have proven acceptable under all applicable tests.

With such specifications and controls, necessary to their effective attainment, established, and keyed to test coupons with standardized evaluation procedure, specific processes and suppliers can, initially, be certified in specific earned classifications. Any process or source meeting specifications and applying acceptable controls and at-source inspection could be certified. "Casting factors" could be progressively reduced and, if possible, eliminated. New casting alloys, established by physical testing of materials of different chemistry with controlled structure, will undoubtedly be developed. Much metallurgical development is at hand which can be utilized to provide improved physical properties under such controls.

11.[redacted] <u>RE: COMPARATIVE ECONOMICS OF CASTING PROCESS</u>:

A. <u>That</u>: the pouring of metal directly to close approximation of size eliminates the employment of large and costly steel mill equipment, eliminates large and costly forging equipment, the related power and labor, and the heating processes involved.

B. <u>That</u>: machining of even rough commercial castings, as compared to forgings, is very greatly reduced.

C. <u>That</u>: finish machining of dimensionally controlled castings represents a material saving. Elimination of material waste, reprocessing, and transport is obvious.

D. <u>That</u>: much "melting stock" useable in castings is available. Foundries are broadly distributed geographically and can obtain a high percentage of raw materials from local sources, reducing handling, transport, and motion, and providing closer control of raw materials.

E. <u>That</u>: such decentralization of casting facilities in small units makes economic use of national power supply as well as reducing vulnerability to attack.

F. <u>That</u>:

1. Pattern facilities are available in large number and wide dispersion.

2. Such pattern shops, in general, employ crude and outdated equipment

and can be greatly expanded in output with improved tooling and small facilitation.

3. "Pattern-dies" ("hard" metal, bronze, steel or stainless steel patterns) can be greatly accelerated in production by employing advanced casting processes to cast them to close approximation of final finish.

4. Processes currently employed for finishing glass molds, employing semi-skilled labor, are available and can be utilized.

12. SPECIFICATIONS:

A. That: current Government and aircraft specifications will serve to impede rather than aid the effective utilization of castings produced by advanced processes.

B. That: they currently omit grain size and chemistry-structure specifications and do not include a variety of applicable specifications that must essentially be applied to high integrity castings to ensure progressive reduction and elimination of "casting factors".

C. That: Contractor's work on (a) mold and casting surface controls and inspection procedures, (b) integrally cast test coupons keyed to Comparoscope and other advanced methods of evaluation, (c) as-cast test bars realistically related to metal sections and mold conductivity, are all beneficially applicable, with reasonable effort, to the creation of improved and more realistic process and inspection controls.

13. "CASTING FACTORS":

A. That: aircraft industry experience, historically, with castings in general and light metal castings in particular, has proven that castings vary greatly in soundness, cleanliness and physical properties (a) in different sections of the same casting, (b) between individual castings obtained from the same producer and poured on the same heats, and (c) between castings made to the same pattern and produced by different producers.

(NOTE: This is indisputable, and Contractor is in agreement with such findings. They would not be seriously disputed by any representative of the casting industry. It can be argued and, in some instances, well documented that aircraft inspection is unrealistic and that it is possible to produce castings with very inferior properties, particularly grossly large grain size in local areas and high structural irregularity generally, to pass X-Ray and other aircraft inspection. It has been accurately stated by aircraft engineers that entirely functional and dependable castings can be rejected by application of aircraft inspection which is demonstrably unrealistic in some respects.)

B. <u>That:</u> it can be proven that design, proven satisfactory in other process, is a factor in the shortcomings of castings. Apart from all controversial aspects, it is obvious to all concerned that the attainment of predictable uniformity in castings is the prime objective of both aircraft and casting industry, that all Government-sponsored and private research is directed largely, or in part, toward this objective, and that considerable progress has been made.

C. <u>That:</u> reduction of "casting factors", by which castings are arbitrarily devaluated in permissible design loading, will stand as a major obstacle to employment in aircraft until the progressive reduction and elimination of such factors can be tangibly justified.

D. <u>That:</u> the reduction of such casting factors are, in substance, equivalent to an increase in properties, permitting the greatly increased employment of castings in many aircraft applications.

E. <u>That:</u> any realistic and potentially effective effort to bring about the reduction of casting factors by the integrated employment of (a) casting design-process technology, (b) advanced casting process, (c) realistic reorientation of Government and aircraft casting specifications (supported by adequate process controls and testing procedures) will require thoroughgoing cooperative effort by Government agencies, aircraft industry, and casting industry.

F. <u>That: time lost in effectively instituting, implementing, and supervising such cooperative effort will directly delay and most effectively impede all other constructive effort on Casting Potentials.</u>

14. <u>DIRECT SUBSTITUTION OF CAST COMPONENTS IN PRODUCTION AIRCRAFT HOLDS MINIMUM POTENTIAL:</u>

A. <u>That:</u> direct interchange of cast components for present components (whose form has been determined by (a) designers' experience with other processes, and (b) specific technical requirements and limitations of other process, provide a minimum opportunity to employ castings in existing aircraft.

B. <u>That:</u> further limitations are imposed by the fact that such existing forged and/or fabricated components are:

1. Integrated into complex assemblies.

2. Attached to contacting areas of adjacent components, designed for attachment to specifically conforming mating surfaces, which demand conformation in form and principal and/or detail dimensions, substantially duplicating or closely simulating the original component.

3. A variety of auxiliary equipment, hydraulic controls, assorted "plumbing", wiring, etc. are designed or "grew" to nest into all available space on, and in, the original components. (These can often be rearranged to advantage.)

C. That: apart from above considerations, effort expended in attempting to duplicate components in adequate supply on current production aircraft is largely a waste of time and money because the probability is that aircraft will be obsolete before design, production, testing and acceptance of cast component is completed.

15. CASTINGS MUST BE INCLUDED IN DESIGN CONCEPT:

A. That: the acceptable, logical or effective, - thus mandatory, - approach to evaluations of Casting Potentials in aircraft is to incorporate cast components, designed with full utilization of casting design-process technology, in new aircraft and missile design prior to the "freezing" of design for production by other processes.

B. That: such casting design must be currently and cooperatively developed with, and as part of, the basic design concept of such new aircraft.

16. CONCLUDING CONCLUSIONS:

As repeatedly stated, the principal deterrent to open-minded understanding and evaluation of Casting Potentials is psychological and is invariably in inverse proportion to the understanding of advanced casting technology. Casting potentials in aircraft can not be evaluated by past experience with the product of jobbing foundries or conventional casting process generally, any more than aircraft of today and the future can be evaluated by the "Jenny" or the B-36.

Basically, very little is "wrong" with conventional casting practice in serving the markets which it has developed, to grow to the nation's second largest metal industry. Such castings have been very extensively used in aircraft and are currently being successfully employed in large numbers on certain aircraft applications. It is obvious that the aircraft industry, stimulated by enemy competition and highly subsidized by Government has, of necessity, advanced far beyond the casting and many other basic industries. There is a minimum of commercial incentive for the foundry industry, in general, to seek aircraft business, particularly when it is profitably employed in serving basic industries with indefinitely continuing requirements. There is less incentive for the casting industry to become integrated in the aircraft industry economic cycles or to become a step-child of the Government. The problems presented in obtaining the active cooperation of the casting industry in development and supply of aircraft castings represent a major obstacle. Some interest is developing. Refer to Objectives, this report, as they relate to the casting industry. Formidable obstacles from the casting industry viewpoint, and otherwise, are Government and aircraft specifications, aircraft procurement and inspection procedures, lack of controls necessary to meet specifications, and many other considerations which can be readily resolved by typical American teamwork.

A substantial beginning has been made through the foresight and technical acumen of individuals in the Military, the aircraft industry, and the casting industry in activating, broadly, this and related casting potentials effort. The support accorded this minutely budgeted effort by men of good will and unquestioned qualifications, as represented by the Project Advisory Committee and broadly beyond, is unique and unprecedented in a project of this size and type. It is believed that this group has all of the psychological, technical, production and economic problems properly oriented and in reasonable perspective.

At this point, it can be safely stated that seeds have been planted. Even sprouts may have a far-reaching significance to U. S. air power. In any case, a sound objective and dedicated nucleus has been formed which serves no selfish interest. How it may be employed to assemble and integrate applicable technology, imaginative thought, and constructive effort,directed to the full employment of casting technology against our enemies, is a matter for the Air Materiel Command to determine. The Recommendations hereinafter submitted do not include the detail and elaboration which has been included in this report, at the risk of criticism, in recognition that this effort is primarily educational. Amplification of the Recommendations and, if desired, detailed engineering presentation of procedure, technology and facilitation considered pertinent to their attainment will be submitted on request.

<u>CONCLUSIONS</u>:

A. <u>That</u>:

1. Very material upgrading of substantially all castings currently employed in aircraft can be expediently effected by employing one or more various advanced casting techniques, singly or in combination, in foundries currently producing such components.

2. Various degrees of facilitation will be required.

3. Advanced controls and at-source inspection, equivalent to aircraft plant inspection, should be established.

B. <u>That</u>: full employment of advanced casting process can best be accomplished with entirely separate facilities and with specially trained personnel, preferably in the foundry industry, but equally applicable elsewhere.

C. <u>That</u>: melting and cleaning, and possibly other facilities, in many steel foundries can be effectively utilized by:

1. Producing molds as an entirely separate and isolated operation.

2. Pouring such molds from metal available to adequate melting and temperature controls.

3. "Finishing" the castings with existing and additional facilities as required.

D. That: ceramic molds can be produced advantageously in many localities employing a high percentage of local materials, labor, and kiln facilities, and transported, as desired, for pouring wherever metal is available.

E. That: aircraft companies currently employ engineering and production personnel in their tool operations and have facilities adequate for the production of pattern-dies and for all of the special equipment which may be required in production of castings within limit of size.

F. That: such advanced casting facilities can be installed in any aircraft or component production facility, or elsewhere, in any light metal manufacturing area.

G. That: advanced casting practice employing Contractor's process and certain other processes bear small resemblance to conventional foundry facilities in that:

1. No molten metal is carried.

2. No smoke or health hazards exist.

3. No "foundry" skills are required, as the "brains are in the tooling".

H. That: casting process for production of aircraft wings, "fins", large structural components, entire missiles, etc., with substantially no size limitation, is a specialized operation and, in general, much simpler of accomplishment employing:

1. Metal molds where applicable, and ceramic molds otherwise on aluminum, and ceramic molds on steel.

2. Employing ceramic cores in processes other than the "Coreless Casting Concept" previously presented by Contractor.

I. That: process for the production of such large components is relatively simple as compared to "jobbing" casting process, and entire facilities will be unitized, requiring a minimum of floor space and supplementary services.

SECTION V - CONCLUSIONS AND RECOMMENDATIONS

- RECOMMENDATIONS -

It is Recommended that the effort known as Casting Potentials Project be extended as follows:

PHASE I:

A. CASTING DESIGN-PROCESS MANUAL:

To prepare a Casting Design-Process Manual to comprehensively present casting design-process technology. Objectives:

1. To provide Aircraft Designers with basic and detailed information on casting design process technology, thus facilitating understanding, acceptance, and effective employment of such material in aircraft design.

2. To provide Casting Designers with current information on proven and projected advances in casting technology applicable to production of aircraft components, and broadly applicable in the casting industry, to the benefit of defense production generally.

B. ENGINEERING & PRODUCTION EFFORT:

1. Design several aircraft components for new aircraft (a) logically and preferably integral with the overall design concept at its inception, (b) certainly prior to the freezing of design beyond practical alteration to permit design of cast components with full employment of advanced casting design-process technology.

2. To pilot produce cast components for such new aircraft to such designs in steel and aluminum, by advanced process, with facilities currently available and with such minor supplementation as may be indicated as necessary to produce parts finally selected. (See Notes 1, 2, and 3.)

NOTES:

1. Proposals have been made by Contractor to AMC substantially in accordance with the above recommendations and closely approximating Contractor's original proposal described as Alternative A. "The Job As We Believe It Should Be Done", presented to AMC in response to request to bid, under date of October 21, 1950.

2. Casting processes projected for employment, where applicable, on above recommended effort are, in part, Navy developed and, in part, proprietary process of Contractor and/or General Alloys Company on which patents are pending, and are subject to customary license agreements with the Armed Services.

3. The Bureau of Aeronautics has approved, and Contractor proposes to employ, as applicable, integrated Navy and Company owned facilities at Champaign. Such facilities were, in part, supplied on joint BuShips and BuAer projects which began in 1947, and are currently being materially expanded under Bureau of Aeronautics Facilities Contract (with Army Ordnance participation) to constitute a casting research and development, and pilot production facility of the Bureau of Aeronautics.

Section V (continued)

3. To concurrently produce steel landing gear component of Chase Aircraft from design herein reported, by Contractor's advanced casting process, and test same, together with forged component.

4. To evaluate casting potential of large landing gear components, including Douglas component herein reported, and, if potential justifies, (a) select specific component, and (b) redesign same as a cast steel component, (c) pilot produce such component, (d) stress test the cast and the forged components together under identical load conditions, with loads realistically simulating service loads.

5. (a) To design cast components for a new missile, in maximum integration with overall design concept and maximum freedom to fully employ casting design-process technology.

   (b) To pilot produce such designs as cast components.

PHASE II:

LONG RANGE PLANNING:

A. It is recommended that, coincidental with Phase I, the Commanding General of Air Materiel Command consider, and make such provision as his judgment may indicate, the calculated probable or possible role which castings may, potentially, perform as a contribution to U.S. aircraft supremacy.

B. In proportion to his evaluation of Casting Potentials in aircraft and missile technical advancement, producibility, and economics, and whether considered as a major factor or as a second or third alternative to other processes, long range planning is indicated.

C. On the assumption of AMC acceptance of a reasonable probability or possibility of acceptable application of advanced casting process to aircraft production, Contractor respectfully submits that time is the essence, and that engineering studies for design of new aircraft and missiles should be undertaken in collaboration with the casting potentials effort directed at:

   1. The maximum incorporation of cast components in alternative designs of aircraft currently projected.

   2. An imaginative all-out design effort to create an entirely new aircraft design fully incorporating all projected casting potentials.

Both efforts, and particularly the latter effort, (starting from "whole cloth"), is recommended to avoid years of time which would be lost through "nibbling" at

Casting Potentials. The fact that the ideas presented are revolutionary in concept does not alter their technical integrity or their probability of attainment.

Comment:

Even a marginal possibility of expediting obsolescence of enemy aircraft and production facilities is believed to far transcend the other considerations involved.

PHASE III:

Coincidental with effort recommended as Phases I and II, it is recommended that AMC initiate a conference of Military and Aircraft personnel to review and consider, in technical detail, Contractor's presentation of a projected new process, (identified as Process "H-X"). Process differs radically from Contractor's process previously presented or discussed. Such process can not be accurately described as "casting" (in the sense that the term has been heretofore employed). Process H-X is intended to produce light metal components of substantially unlimited size directly from fluid to solid metal, employing principles of physics and metallurgy which have not, to Contractor's knowledge, been previously presented or explored.

Process H-X is based on the application of fundamentals in physics, metallurgy, hydraulics, and mechanics which, when integrated into process, appear to hold great promise. Basically, subject process is believed, - after mature consideration of nationally known and broadly qualified engineers outside of Contractor's organization, - to provide the maximum visible possibility of producing, without forging of solid metal, the three principal advantages which light metal forgings are considered to hold over light metal castings (and are responsible for the superior properties of forgings). These are:

A. Residual effects of "work".

B. Relative freedom from contained oxides.

C. Greater and more uniform density.

PROJECTED ADVANTAGES OF PROCESS H-X:

As projected, Process H-X employs greatly reduced pressures which permit the use of dies and facilities costing a small fraction of comparative costs in the production of large forgings. Further, such dies and production equipment can be expediently produced at low cost, and in any desired quantity, by employment of existing facilities.

The process, as projected, is relatively simple. The principles on which it is based, and their applied effectivity, can be evaluated at low cost, with relatively simple experimental facilitation.

Section V (continued)

Process H-X is believed to possess the unique advantage that, should it prove applicable to the production of a part of relatively small size and area, it is directly and proportionally extensible to any size product within visible requirements.

It is recommended that evaluation of subject process be highly restricted due to the extreme simplicity of the basic concept. At the discretion of the Commanding General, Contractor will prepare and graphically present, at private expense, principles and essential detail of process H-X to Commanding General for his consideration.